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Nonpoint Source Pollutant Monitering on the Ponaganset River Watershed

John C. Arruda Jr.
University of Rhode Island

NONPOINT SOURCE POLLUTANT MONITORING

ON THE

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JOHN C. ARRUDA, JR.

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JOHN C. ARRUDA, JR.

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Thesis Committee

Major Professor Raymond M. Wright

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ABSTRACT

The Ponaganset River Basin consists of an area of 14.4 mi^2 located in the town of Foster, Rhode Island. This area is located within the northwest region of the Scituate Watershed. The source of this river comes from the Ponaganset Reservoir with an area of 2.1 mi^2 and a storage capacity of 742 MG. Water quality samples were collected at United States Geological Survey (USGS) site (01115187) which is approximately 5 miles down stream from the reservoir and 0.4 miles upstream from Barden Reservoir. The Ponaganset River has the largest mean daily discharge of all the sampling locations in the Scituate Reservoir watershed.

The concept of this analysis originated with the 1995 Water Quality Protection Plan which sited a lack of wet weather data on the Scituate Reservoir Watershed. No wet weather data was collected from the watershed between 1995 and 2003. In 2003, the Water Quality Protection Plan again sited a lack of wet weather data on the Scituate Reservoir Watershed as one of the major weaknesses. The plan recommended the need to determine potential wet weather impacts as well as the potential sources of those impacts on the environment.

The objective of this analysis was to determine non-point sources of pollutants which contribute to the river and establish a preliminary wet weather monitoring program to determine pollutant loads contributed by stormwater runoff. In addition, this analysis was intended to establish a procedure to extrapolate wet and dry weather data from a characteristic sub watershed to the entire Scituate Watershed. In this study, the Ponaganset River site was selected

based upon preliminary research, historical water data, and range of flows for the selected site. The data collected during wet weather sampling provided insight into the behavior of the sources during various storm events as well as storm characteristics. The information acquired for use in this analysis was used to explore load characteristics using linear and multiple regression models to predict loads then apply them to monthly and annual parameter data to determine if the site is either influenced more with dry weather or wet weather.

As more stringent water quality standards continue to increase, monitoring the health of the watershed will increase as well. Evaluating the water quality under dry and wet weather conditions seems fitting to answer some of these questions in addition to fulfilling the requirements of this thesis. In this study, water quality results, loads, and linear/multiple regression models are used to determine load characteristics that exist at this site and to relate this information to the entire watershed.

The field data used to develop the statistical models was conducted solely by the investigator and all samples were tested by Premier Laboratory in Dayville, Connecticut. Sampling and monitoring for the analysis occurred for a period of approximately two years during the months from April to September in 2005 and 2006. Three wet weather events were successfully captured for the wet weather program: Storm 1 (May 2-4, 2006), Storm 2 (July 12-14, 2006), and Storm 3 (September 19-20, 2006). A total of twelve dry weather samples were collected between April through August 2005 and May through September 2006. The initial samples collected consisted of total suspended solids (TSS), biological oxygen demand (BOD), inorganic constituents, total trace metals, and nutrients. During sample collection the introduction of errors was always a concern and careful consideration was taken to avoid any contamination to the water samples. A strict regimen of water sample collection techniques, preservation, and laboratory analysis were carefully adhered to avoid any contamination.

Concentration data and flow data were used to calculate the mass load. With the use of the water quality data collected at the site, it allowed for the development of empirical equations used to determine dry and wet weather loads. Linear regression models were developed for dry weather and multiple linear regression models were developed for wet weather conditions for selected constituents. The six primary constituents included barium, manganese, aluminum, iron, sodium, and chloride. A limited amount of total coliform bacteria data was also included in the analysis. The largest loads observed at the site included sodium and chloride during wet weather conditions. The equations were later applied to hydrograph data which had been generated for a period of a year that occurred from October 1, 2003 to September 30, 2004. Although the data set used to develop the models was limited to twelve dry weather samples and three storm events, the data showed that it could be applied to the monthly and annual parameter data used to describe dry and wet weather load characteristics for this sub-watershed. The application of the mathematical models indicates that the Ponaganset River watershed is both dry and wet weather influenced. Finally, the analysis provides a procedure to determine annual loads and provide recommendations for future wet weather assessment for the entire Scituate Reservoir.

Further evaluations of wet weather monitoring within the Scituate Reservoir Complex will be needed to access the overall health of the watershed. A team effort is needed as planning is crucial in order to gather accurate data. The findings of this analysis may lead to a more extensive wet and dry weather analysis encompassing the entire watershed.

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I would like to acknowledge my utmost gratitude to those people who have helped me to successfully achieve the completion of this thesis:

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Others whom I work with at the Providence Water Supply Board have also greatly assisted me in endless questions I have had through the various stages of this thesis that include: Frank Healy, Steve Soito, Chris Labossiere, & Nancy Crosby. Frank Healy has been the one individual who has helped me through many stages of this project and I'm truly grateful for all his support. I would also like to thank my supervisor, Peter Le Page and the Director of Engineering, Paul Gadoury for their help in completing this degree and also a special thanks to Providence Water Supply Board for funding and assisting in my efforts to accomplish a Masters Degree at the University of Rhode Island.

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CHAPTER 1

1 INTRODUCTION

1.1 History

The Scituate Reservoir was constructed in the early 1900's due to the growing need of a fresh water supply for the City of Providence. Under the administration of Joseph H. Gainer, Mayor of the City of Providence from January 6, 1913 to January 3, 1927, Gainer Dam and the Scituate Reservoir were planned and developed by the Providence Water Supply Board (PWSB). In 1927, work associated with the construction of the Water Purification Works, Gainer Dam and the adjoining tributaries of the reservoir were completed.

Daily rainfall measurements have been conducted on the Scituate Reservoir Watershed since November 1, 1915. The first rain gauges were installed in the reservoir areas known as South Scituate, Hopkins Mills, and Rocky Hill. Additional gauging stations were added at Fiskeville on February 20, 1916. On December 3, 1925 two more stations were established at North Scituate and south of Gainer Dam. The gauging station located in South Scituate was discontinued on November 9, 1925. On September 17, 1928 Westcott was added due to the growing need of a station located in close proximity to the center of the watershed. The rain gauges at the five locations are measured daily at 8:00 AM and the summations of these readings are then averaged for the day.

1.2 Scituate Reservoir Watershed

The Scituate Reservoir watershed is located on the North Branch of the Pawtuxet River in the Town of Scituate. The location of the watershed is located in the northwest region of Rhode Island. The watershed is 92.8 square miles and is composed of five tributaries (Ponaganset, Regulating, Moswansicut, Barden, and Westconnaug Reservoirs) in Figure 1.1. The direction of flow in the Scituate watershed flows from north to southeast to the Scituate Reservoir.

Figure 1.1: Location and Hydrology of the Scituate Reservoir Watershed (Nimiroski and Waldron, 2002)

Regulating Reservoir was constructed as an emergency supply during the development of the Scituate Reservoir to regulate the flow of the Pawtuxet River. The other four main bodies of water existing prior to the development of the Scituate Reservoir are Moswansicut, Westconnaug, Barden, and Ponaganset Reservoirs. These five tributaries all flow into the main reservoir known as the Scituate Reservoir, which has a total storage capacity of approximately 41, 268 million gallons when filled to capacity, which includes the dead storage. The total available storage, representing the amount of water that can be drawn by gravity totals 39,746 million gallons. There is approximately 5,120 acres of water surface on the watershed, Scituate Reservoir with 3,632 acres, Regulating Reservoir 242 acres, Moswansicut Reservoir 282 acres, Westconnaug Reservoir 174 acres, Barden Reservoir 240 acres, and Ponaganset Reservoir 245 acres when they are filled to their respective flow lines. Other smaller bodies of water include several smaller reservoirs, ponds, brooks and swampy areas, which account for the remaining balance (Ingham 1970).

The Scituate Reservoir supplies the water demand to several cities and towns in Rhode Island including East Smithfield, West Warwick, Cranston, North Providence, Providence, Johnston, and Bristol. It is estimated that the Scituate Reservoir complex provides potable water to approximately 60% of the residents of Rhode Island. The majority of the land within the watershed is primarily made up of forest and undeveloped land. Land use in the entire watershed from an updated analysis completed in 2002 with USGS in conjunction with PWSB determined 64.3% consists of forest, 10% wetlands, 8% water, 11.6 residential, 4% agricultural, 1.4% nonresidential urban, and 0.7% other which encompass the entire watershed complex (Nimiroski, DeSimone, and Waldron 2008). The topography of the drainage area consists of steep slopes, rolling hills, and large rock outcrops. Land slopes greater than 10 percent are found in about 20 percent of the basin (Breault and others, 2000). The watershed is primarily composed of well-drained soil, while poorly drained areas consist of approximately 17 percent of the basin. The bedrock in this watershed is mainly composed of Devonian and late Proterozoic igneous and metamorphic rocks and is overlain by glacial deposits consisting of till and meltwater deposits. Till covers most of the watershed, where meltwater deposits such as sand and gravel are limited to stream valleys and low-lying areas (Breault and others, 2000).

Of all the sampling located situated throughout the Scituate watershed, the Ponaganset River has been described as one of the principle streams in the basin which has been indicated in several USGS publications such as (Nimiroski, Waldron, 2002) and (Nimiroski, DeSimmone, and Waldron, 2008). Historically, the range of flows at Ponaganset River (site 0115187) vary from 0 to 1,110 cfs during the period of WY 1994 though 2006 at the site. During water quality sampling for the analysis in WY 2005 and 2006 the average daily flows were 29.6 and 41.5 cfs respectively. The sites real-time monitoring capabilities with regard to discharge and precipitation monitoring capabilities led to investigate this site more closely in 2003.

CHAPTER 2

2 BACKGROUND INFORMATION ON STUDY AREA

Background information is provided as a means of describing the preliminary research performed, which led to the evolvement of selecting this site for this analysis. First, the entire Scituate Reservoir Watershed was evaluated for precipitation records from data provided by Providence Water for fiscal 1996 to 2002 to compare methods of determining total rainfall on the watershed. The second phase of this preliminary research included a runoff analysis of the Ponaganset River Basin near South Foster (site 01115187) Rhode Island. In this preliminary analysis, information from daily rainfall records were used in conjunction with discharge (cfs) measurements to determine the effective runoff characteristics within the Ponaganset River Basin. This research assisted in developing the duration, antecedent dry period, and total rainfall patterns at the Ponaganset site.

2.1 Rainfall Analysis of the Scituate Reservoir Watershed

During preliminary research of the Scituate Reservoir Watershed daily rainfall records were obtained through PWSB watershed management. The precipitation data utilized for the analysis occurred from 1996 to 2002 using PWSB fiscal data for the five rain gauges (Rocky Hill, Hopkins Mills, North Scituate, Westcott, and Gainer Dam). Each of the five rain gauges is measured at approximately 8:00 AM daily. The rain gauges located at Rocky Hill, Hopkins Mills, North Scituate, and Westcott are located in the backyards of individuals owning homes within the PWSB watershed. The rain gauge labeled "Gainer

Dam" is situated at the PWSB Treatment facility. The locations of these five rain gauges are shown in Figure 2.1:

Figure 2.1: Locations of Rain Gauges and Ponaganset River Site in the Scituate Reservoir Watershed (Nimiroski and Waldron, 2002)

The data used for comparing the Thiessan method was obtained through contacts at the United States Geological Survey in 2003. This method had already been determined for the percentages of contributions for each rain gauge from a previous saltwater study of the Scituate Watershed with the use of Geographical Information Systems (GIS).

Comparison the two methods indicated that the t – statistics in the entire daily, monthly, and yearly data point to a strong relationship of linear association between x and y proving that either the Thiessan or Arithmetic methodologies are satisfactory to account for the rainfall on the Scituate Watershed. The comparison of methodologies identified the following results:

- When one inch or less of rainfall fell on the watershed, the Arithmetic and the Thessian methodologies were similar and indicated little deviation between values.
- When greater than one inch of rain fell on the watershed, the Arithmetic and Thessian methods were not similar and indicated a greater deviation between values.

In comparing the standard practices of PWSB's arithmetic methodology, rainfall data is usually described on a monthly and yearly basis for their annual reporting, but to identify specific storm characteristics, real-time precipitation are very important.

2.2 Preliminary Research of the Ponaganset River Site

The initial evaluation entailed determining runoff characteristics for selected storms in conjunction with rainfall data provided by PWSB. This was completed prior to visiting the site location. The criteria for storm selection required a minimum 0.25 in. of precipitation having a dry day before and maintaining a dry day after the storm event. The evaluated storms occurred from

October 1, 2001 to September 30, 2002. The discharge data was provided by United States Geological Survey (USGS) in real-time fifteen-minute interval discharge (cfs) reading. From the criteria, stream flow hydrographs were selected at a more defined search. The selected time frame excluded winter months (November 2001 through March 2002), because of the occurrence of snowfall within that time period. A total of 24 hydrographs were evaluated for the site. Later, further elimination was done based upon the shape, amount of precipitation, and if antecedent moisture conditions occurred before and after the storm event. After filtering the remaining hydrographs, a total of 15 storms (Table 2.1) were selected for computation of the actual unit hydrograph using methods described in Gupta (1989). The direct runoff volume (V) was determined by subtracting the difference of the discharge minus base flow using the concave method of base flow separation then summing the direct runoff for the entire storm. The concave method (Figure 2.3) separates the base flow by extending the recession curve before the storm at the initial base flow where the discharge begins to increase to a point directly below the peak discharge (time to peak). From this point a straight line is then extended to a point on the discharge hydrograph at 41 hours after the peak in the river. The 41 hour duration (N) was determined by multiplying the drainage area (A) in square miles (14.4 mi^2) using the formula:

$N = aA^{0.2}$ where $a = 1$ if the drainage area is determined in square miles. The runoff depth (P_n) of the storm event was divided by each ordinate of the direct runoff to finally obtain the actual unit hydrograph, since storm duration was unknown. In section 6.2, these parameters are described for the storms that were evaluated for the analysis in Table 6.1. Table 2.1 describes the runoff characteristics for the storms that were evaluated for the analysis.

Table 2.1: Summary of 15 Storms Evaluated at the Ponaganset River Site 2002

#	Date	V	Duration	Pn	P_T	Q_{MAX}	Base Flow	$Q_{MAX-B.F.}$	Effective Runoff
		(cfs)	(hrs.)	(in.)	(in.)	(cfs)	(cfs)	(cfs)	(%)
1	3/31/02	2071.1	58	0.22	1.00	110.31	21.02	89.3	21.9
2	4/22/02	182.0	69	0.02	0.29	15.51	10.37	5.1	6.8
3	4/25/02	576.3	60	0.06	0.72	32.73	11.77	21.0	8.7
4	4/28/02	1073.0	63	0.12	0.87	52.30	16.51	35.8	18.3
5	5/2/02	931.1	70	0.10	0.53	45.73	15.20	30.5	18.2
6	5/12/02	5650.8	79	0.61	2.74	236.69	10.07	226.6	23.7
7	5/18/02	3272.7	58	0.35	1.67	165.55	23.25	142.3	57.8
8	5/31/02	423.40	61	0.05	0.81	24.60	10.59	14.0	5.6
9	6/12/02	188.0	54	0.02	0.39	22.46	16.30	6.2	4.2
10	6/15/02	300.6	61	0.03	0.65	28.28	18.38	9.9	7.0
11	6/22/02	502.5	58	0.05	1.01	27.48	6.95	20.5	45.1
12	8/28/02	44.3	78	0.005	0.10	1.50	0.10	1.4	0.5
13	9/15/02	130.9	74	0.014	2.37	3.78	0.28	3.5	0.6
14	9/23/02	28.4	62	0.003	0.92	1.44	0.43	1.0	0.4
15	9/26/02	238.5	76	0.03	1.38	6.49	0.59	5.90	1.8
	Max.	**5650.8**	79	**0.6**	**2.6**	**236.7**	**23.3**	**226.6**	**57.8**
	Min.	**28.4**	54	**0.0**	**0.1**	**1.4**	**0.1**	**1.0**	**0.4**
	Ave.	**1040.9**	**65**	**0.1**	**0.9**	**51.7**	**10.8**	**40.9**	**14.7**

* V = Runoff Volume, Pn = Effective Precipitation, and P_T = Total Precipitation

From the summary data of the 15 storms evaluated at the Ponaganset River the duration of the hydrographs occurring from April through September 2002 ranged from 79 to 54 hours. This identified the precedence of establishing a minimum criterion of a two day antecedent dry period for wet weather monitoring analysis. In addition, the preliminary research at this site identified the total rainfall using the average total rainfall for the five rain gauges and the effective rainfall or runoff depth (Pn) which was determined as follows:

$Pn = KV/A$

Where,

Pn = in.	runoff depth of the storm
$K = 1.55 \times 10^{-3}$	conversion factor that converts runoff volume to depth
V = cfs-hr	volume under the hydrograph
$A = mi^2$	the area of the drainage basin (14.4 mi^2)

In Figure 2.2, the probability of reoccurrence for storms based on PWSB rainfall records for USGS Water Year from October 1, 2001 to September 30, 2002 is shown in Figure 2.2. These storms were grouped based upon the consecutive days of rainfall since real-time precipitation records were not available. Evaluation of data from this period indicated a total of 69 storms which ranged from 0.01 in. to 2.64 in. of total precipitation. The majority of storms (63.8 %) ranged from 0.1 in. to 1.5 in. which was used to set the minimum criteria at the analysis site at 0.1 in. of total rainfall for monitoring wet weather conditions.

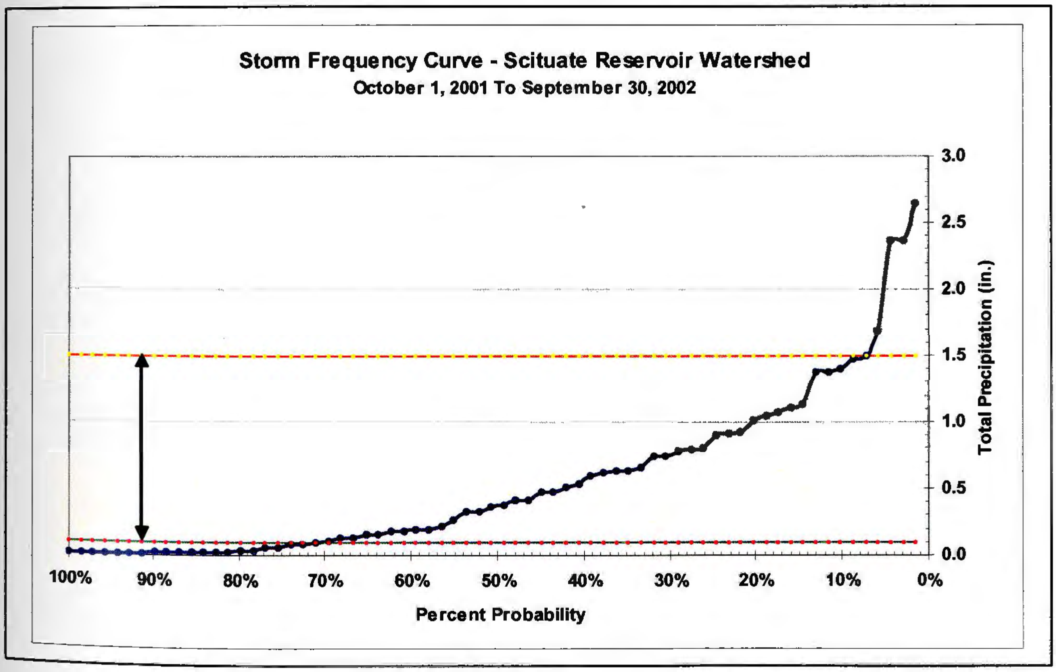
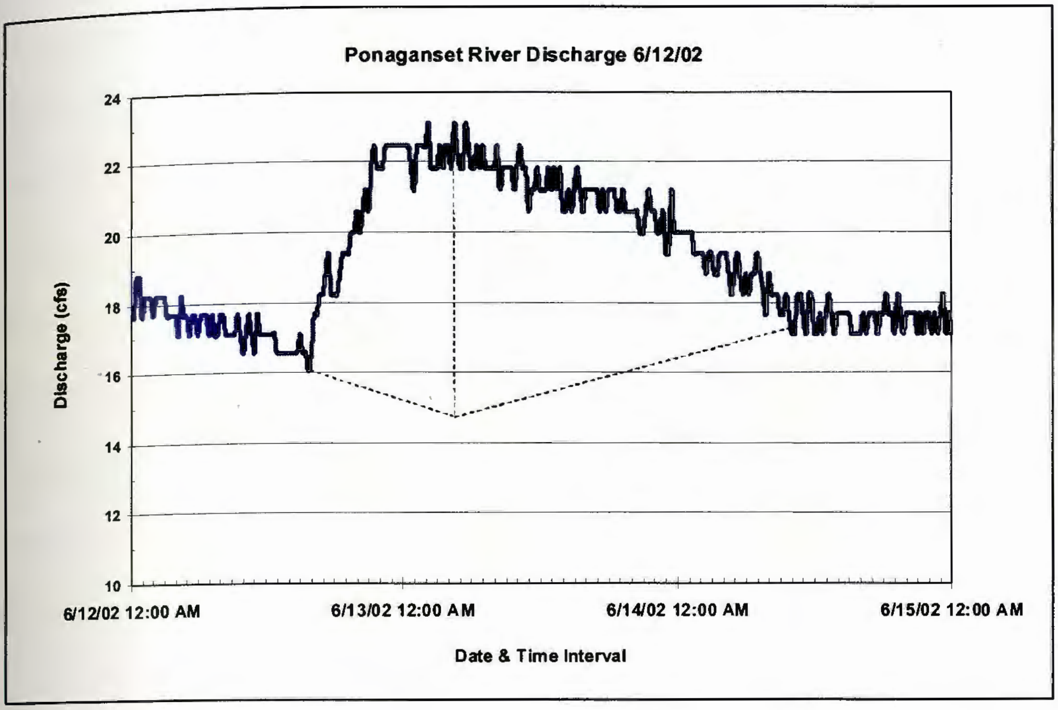


Figure 2.2: Rainfall Probability October 1, 2001 to September 30, 2002

Figure 2.3 is an example of a storm response which occurred on 6/12/02 which had a total precipitation of 0.39 in., runoff volume of 188 cf, duration of 54 hours, and peak discharge of 22.46 cfs. This was one of the smaller storms evaluated. The evaluated hydrographs indicate that the average duration of time it took for the discharge in the river to return to base flow conditions was approximately 2.5 days.



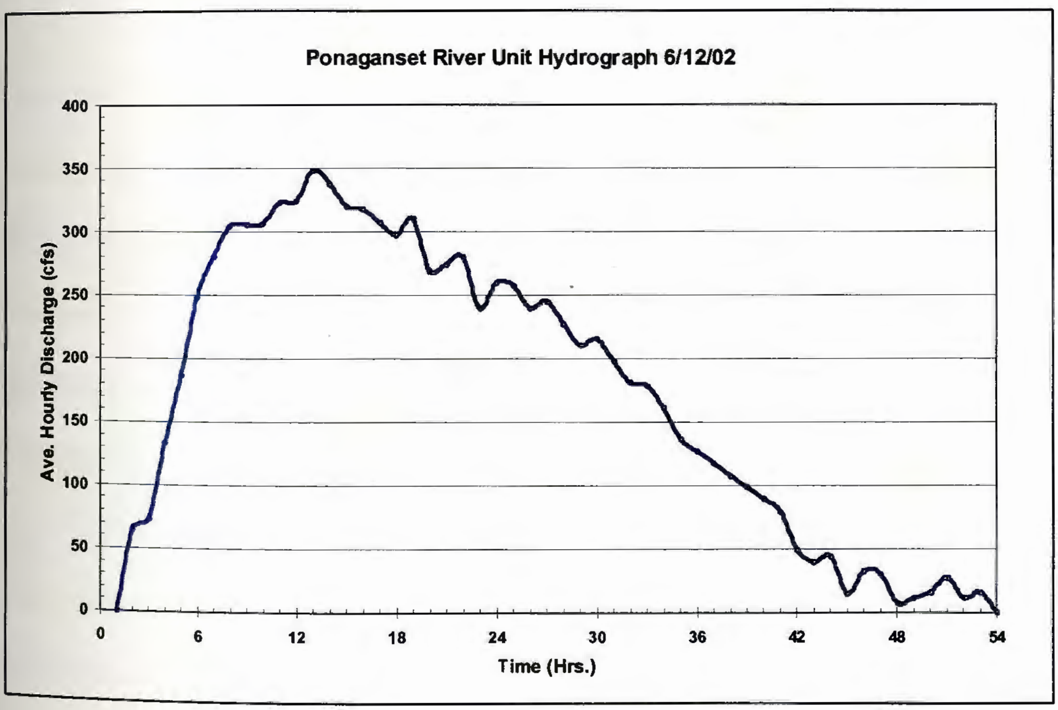


Figure 2.3: Ponaganset River 6/12/02 Discharge and Unit Hydrograph

Researching data for the site identified a significant variation in the total percentage effective precipitation. Results varied from 0.4% to as much as 57.8% which may be due to a number of factors including drought conditions, seasonal changes, antecedent moisture conditions, volume in rainfall, evaporation, and transpiration. Storms with higher effective precipitation occur during periods of intense rainfall in the spring when a large volume under the hydrograph causes a higher runoff depth. The lowest percentages of effective precipitation occurred in September 2002 due to the soil being very dry (category I)(AMC) from the previous summer months. It is believed that during low runoff periods a majority of the rainfall was either intercepted by plants and trees or infiltrated into the ground. Additionally, during periods of low runoff, the storage in the Ponaganset Reservoir was well below the spillway crest causing any precipitation that fell over the basin after evaporation and transpiration to be intercepted and stored. During the summer months, lower effective precipitation is also influenced by thunderstorms, which may cause an unbalanced distribution of rainfall. During the first year of dry weather sampling beginning in April 2005 the rivers discharge was below 1 cfs in August 2005 of that year due to drought like conditions.

The pre-analysis could not predict durations or intensities of storm events due to the precipitation records from PWSB data having only daily 8:00 AM totals for each of the five rain gauges. Several attempts were made to estimate the hourly duration of the storms using Snyder's Method of synthetic hydrographs. This procedure was found to be inconclusive due to C_t & C_p coefficient values. The coefficient C_t represents the slope of the basin varying from 1.8 to 2.2 for distance in miles and C_p is the coefficient indicating the storage capacity varying from 360 to 440 for English units. Through contacts at USGS, a correction publication was found which had a mean slope of the Ponaganset river basin S = 4.6%, which, if used to determine the C_t value, would equal 2.8. This value is much higher than the suggested range of 1.8 to 2.2 for distance in miles. The coefficient of storage C_p was much more complicated to determine. Through discussion with USGS, it was found that the depth of the aquifer of the Ponaganset River Basin was a range of 40 to 50 ft, which is very shallow, along with the lack of gravel beneath the basin surface. This leads to the assumption of using the lowest value in the range of storage coefficients to accurately fit the characteristic description of the Ponaganset river basin. The idea of trying to simulate synthetic hydrographs was to achieve peak ranges from 300 to 400 cfs for a standard duration of net rainfall ranging from 2 to 8 hours then back fit them into the 15 unit hydrographs described in Table 2.1 which occurred from April through September 2002. This portion of the analysis determined that Snyder's Method was inconclusive with respect to the duration of the storm events selected for this report.

2.3 Conclusions of Preliminary Research

Initial evaluation of the Ponaganset River site indicated a range of recovery times for the river to return to base flow conditions, ranging from approximately two to three days. This established that a minimum two day antecedent dry period is required to clearly separate individual storm events. The rainfall analysis indicated that when $\leq$ 1 inch of rainfall fell on the entire watershed (92.8 mi^2), the Thessian versus Arithmetic methods are similar with little to no deviation between the compared values. Larger storms > 1 inch showed a more significant variation between values. From the trends of storms identified during April through September 2002 the total precipitation averaged 0.9 inches which falls within a reasonable range of accuracy based upon the evaluation of rainfall records for PWSB fiscal 1996 to 2002 data. In 2003 real-time precipitation as well as discharge was recorded by USGS. For this reason, historical records could be used to perform a more extensive analysis of this site and correlate its significance to the entire watershed.

2.4 Description of Study Area

The Ponaganset River Basin is located in the upper north west portion of the Scituate Reservoir Watershed consisting of 14.4 square miles, which includes the Ponaganset Reservoir, consisting of an area of 2.1 square miles with a total storage capacity of 742 million gallons. The site is identified as site (01115187) by USGS, site (35) by PWSB laboratory, and site (Py) by the Watershed Management Division. The road lengths for state roads within this sub-basin are identified in Table 2.2:

Table 2.2: Road Lengths for Major Roads within the Ponaganset River Watershed

Road		**Length**
Rt. 6	=	1.12 miles
Old Danielson Pike	=	1.18 miles
Rt. 101	=	3.71 miles
Rt. 94	=	2.92 miles
Anan Wade Road	=	1.45 miles
Totals	=	10.38 miles

The monitoring station is located off Rams Tail Road off Danielson Pike. The site is 0.3 miles south of South Foster and 0.4 miles upstream from Barden Reservoir and is shown in Figure 2.4:

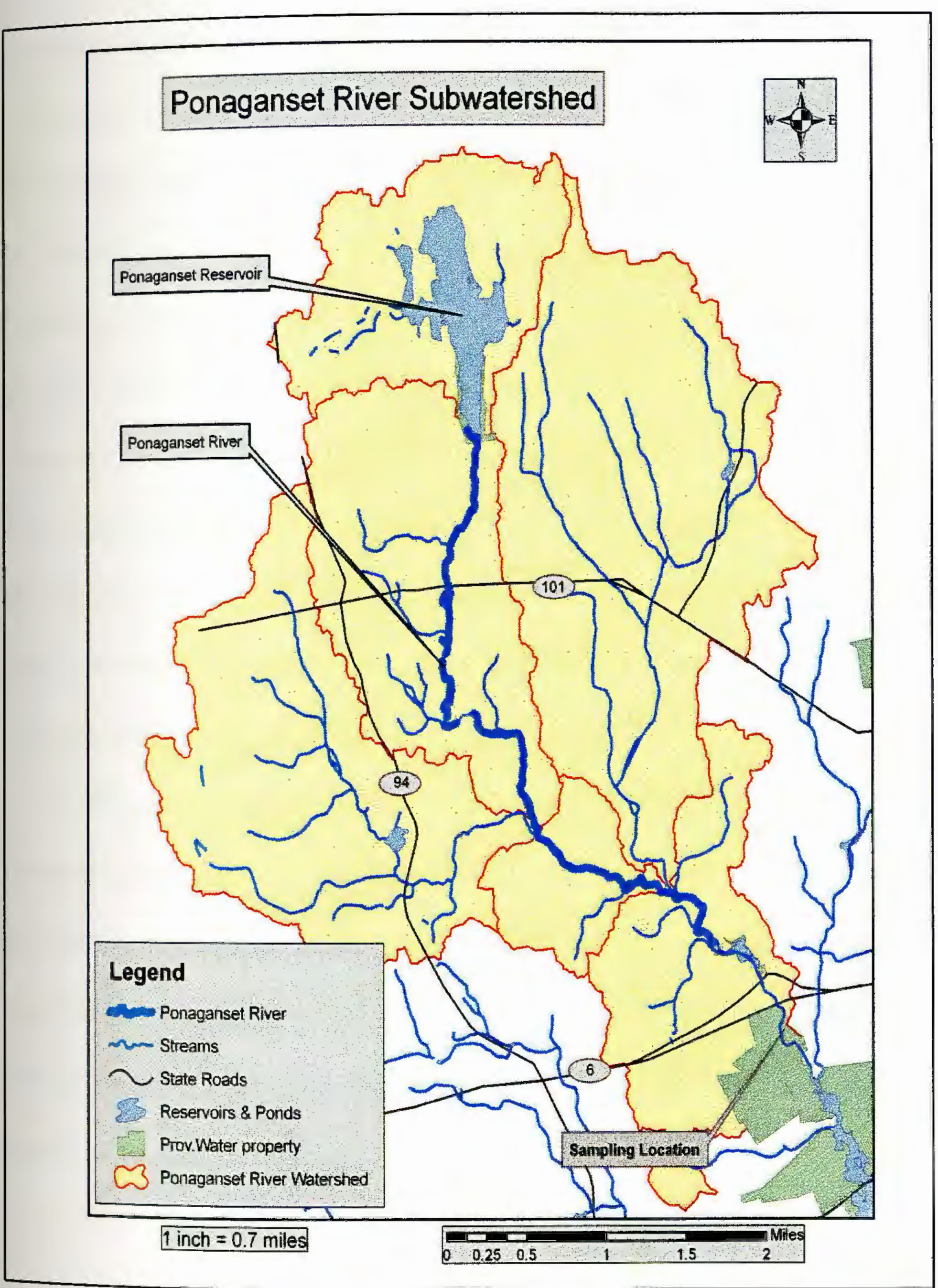


Figure 2.4: Ponaganset River Watershed with State Roads (Blodgett, R. H. 2009)

2.5 Conception of Analysis

The initial conception of this analysis began with research into the types of studies that the Providence Water Supply Board (PWSB) could use as a benefit to a more in depth understanding of the watershed. From reviewing the 1995 Water Quality Protection Plan it was evident that there was lack of wet weather data on the Scituate Reservoir Watershed. It was also cited again in the 2003 plan where it indicated that there was a lack of wet weather data. The plan's recommendations included establishing a preliminary wet weather monitoring program that would allow PWSB to determine pollutant loading contributed by storm water and its relative significance to the watershed. From 1995 to 2009 there has been little to no wet weather data collected on the Scituate Reservoir Watershed. This analysis is designed to quantify water quality characteristics for both wet and dry weather conditions and demonstrated a procedure to predict annual loads for the Ponaganset River site.

The reasoning for choosing this site for the purposes of this investigation is based upon preliminary research into the following site characteristics: location, sample types, variety of samples, historic dry weather sampling parameters, land use, drainage area, historical real-time discharge data with dates back to 1994 to the current year and precipitation totals, preliminary site inspection, and safety in gathering samples.

This site is ideal for analysis such as this, because of its real-time monitoring capability established by USGS in conjunction with Providence Water Supply Board. The data collection capabilities for this real-time station include: continuous fifteen minute interval monitoring for discharge, precipitation, gauge height, specific conductance, water temperature, and air temperature. In this analysis, it was critical to obtain the precise discharge measurements as well as precipitation amounts which were measured at fifteen minute intervals, which can be correlated with the exact time the water quality sample was collected. This data can then be used to determine instantaneous loads and total wet loads by separating out the base flow.

2.6 Site Selection Criteria

The analysis began with identifying all the water quality monitoring sites that are located in the Scituate Reservoir watershed. It was intended at the conception of this thesis that water samples would be collected at multiple site locations although later it was decided to monitor only one site. This research included evaluating records provided by the Providence Water Supply Board (PWSB) laboratory and watershed management division. These records reveal that dry weather data had been collected since 1982 at 37 sites on a monthly basis. In addition, in 1999 approximately 31 more quarterly sampling sites were added to monitor the health of the entire watershed. Each of the estimated 68 sites were evaluated to see which sites were ideal for water sampling during wet weather conditions. Two in particular appeared to be ideal candidates for the purpose of this project. The two sites are the Ponagansett River (site 01115187) at south Foster and Peeptoad Brook (Site 01115098) at Elmdale Road near North Scituate. These two sites are monitored electronically by the United States Geological Survey and are also sampled by PWSB. After reviewing the two sites it was clear that of the two, the Ponaganset River site was the better choice because of its monitoring capabilities such as discharge, precipitation, specific conductance, water temperature and air temperature which are monitored in real time at fifteen-minute increments. In addition, this site is situated in a safe area (Rams Tail Road) off Danielson Pike in Foster. Several preliminary site visits were made to the Ponaganset River site to evaluate the conditions and determine where and how the samples should be taken. At the site located off Rams Tail Road in Foster, there is a wooden bridge that crosses over a narrow section of the Ponaganset River. Below this bridge there are probes with sensors that are mounted below the surface of the water. These probes extend across the river to measure its discharge, specific conductance, and water temperature which is shown in Figure 2.5:

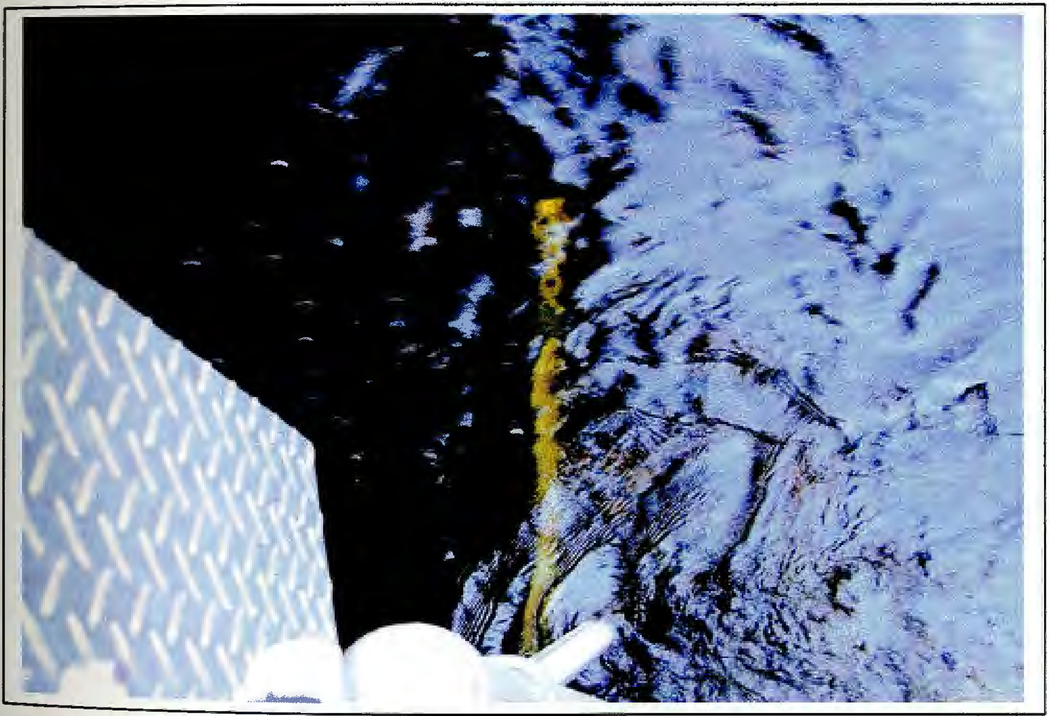


Figure 2.5: Photo of USGS Monitoring Probes Below the Surface of the Ponaganset River at South Foster

This monitoring equipment electronically records real-time responses of the river transmitted to a storage device located in a small concrete building identified in Figure 2.6. In addition, there is a precipitation gauge located on the top of this building (Figure 2.6) with a transmitter that measures air temperature. The real-time data that is recorded at this site is sent instantly through an antenna mounted on the top of the building to a satellite, and then to a server, which sends this information to a website published by USGS in real time format. The delay of this information to users who monitor this site on the internet is approximately four hours. The information that was extracted from the USGS web site was utilized to determine the river characteristics at the time of sampling for both dry and wet weather.

Figure: 2.6: Photo of the USGS Gauging Station at the Ponaganset River at South Foster, R.I. (site 01115187)

The initial determination of where samples would be taken was carefully considered before the first sample was collected at the site. The sides of the river embankment just downstream of the river are steep and somewhat difficult to traverse. During wet weather collection, this would be dangerous for one person to do on their own assuming that with severe rainfall the embankment would become slippery. The ideal location to acquire samples at the Ponaganset River site (site 01115187) is at the center of the bridge shown in Figure 2.7 where it was assumed that the water was thoroughly mixed and samples would be representative of the river conditions. In addition, the monitoring probes that measure the rivers discharge, specific conductance, and water temperature are situated at the same location where the samples were collected. This will provide an accurate representation of the results that correlate with the response of the river.

Figure 2.7: Photo of the Sampling Collection Bridge at the Ponaganset River at South Foster, R.I.

CHAPTER 3

3 WATER QUALITY PROGRAM

3.1 Historic Constituents Tested

Initial research of the water quality at the Ponaganset River site indicated that this site had a substantial amount of historic dry weather samples that have been collected and tested at the site by both PWSB and outside laboratories. The Ponaganset River site is referred to as a Group A and B site by PWSB for the constituents described below:

Group A: Fiscal 1996 to Present
(Tested monthly by PWSB laboratories)

pH, acidity, total alkalinity, color, chloride, turbidity, nitrite, nitrate, total phosphate, total coliform, E. coli, and HPC bacteria

Group B: Fiscal 1999 to Present
(Tested quarterly by Premier Laboratory or R.I. Analytical)

VOC's, SOC's, 8 RCRA metals, copper, zinc, manganese, and vanadium

The abundance of historic water quality records for the this site in relation to all of the other sites monitored by PWSB, real-time precipitation and discharge monitoring, and preliminary research make this site ideal for a preliminary wet weather investigation.

3.2 Water Quality Parameter Selection

The initial set of water quality samples proposed for testing at this site were selected based upon historic data obtained from Providence Water for records that dated back to 1995. In addition to previously tested sampled, some addition parameters were selected from the "Blackstone River Initiative" by Wright, Chaudhury, and Makam (1994) and other studies that have performed similar type analyses.

The following constituents were selected for initial testing as follows: acidity, alkalinity, turbidity, color, dissolved orthophosphate, nitrate, total phosphorous, sodium, chloride, ammonia, fecal coliform, total nitrogen, pH, biological oxygen demand (BOD), and total suspended solids (TSS). In addition, PWSB requested sixteen additional trace metals be included for testing during both dry and wet conditions until it could be determined that they were below detection. The following trace metals were included for testing as total metals: copper, cadmium, zinc, lead, aluminum, nickel, iron, chromium, selenium, arsenic, beryllium, silver, mercury, barium, manganese, and vanadium.

The wet weather data collected from the site was limited to three storm events having a total rainfall depth of greater than 0.1 inches and an antecedent dry period of a minimum of two days. The frequency of sampling under wet weather conditions was decided on a case by case basis in relation to the type of storm event but, was adequate to fully cover the initial, peak, and tail end of the storm event hydrograph. In addition, twelve sets of dry weather samples were taken during the months of April to September of 2005 and 2006. The first dry weather sample was collected on April 15, 2005 and the last was collected on

September 28, 2006. As for the wet weather events, multiple samples were taken over the period of the storm event.

The first storm event occurred on May 2-4, 2006 for which 10 samples were collected. All samples tested for this analysis were analyzed by Premier Laboratory located in Dayville, Connecticut. The first storm event had a total rainfall amount of approximately 1.38 in. with a duration time of approximately 13 hours. For this storm event, 10 sets of samples were collected at intervals of approximately 4 to 6 hours apart for the first 8 sets of samples and the last 2 sets samples were collected at approximately 8 hours apart. The reason for selecting these sample intervals was based upon the predicted forecast for that specific event and the anticipated duration of the storm. Other storms events that were measured, such as storm event 3, were collected at shorter intervals apart (1.5 to 3 hrs.) due to the intensity (0.24 in./hr.) and duration of the storm (5 hrs.).

The resulting samples collected for the first storm event provided evidence that the majority of the initial constituents tested indicated results below detection limits, therefore these were eliminated from the sample set. The detectable constituents included barium, zinc, manganese, copper, aluminum, sodium, and iron. In addition, acidity, alkalinity, turbidity, color, chloride, pH, total suspended solids, and total coliform were monitored at the collection site. The water quality data was analyzed for consistency and instantaneous loads were calculated in lbs./day. Later in this report, the data will be used to predicted load equations using linear and multiple regression model equations. Based on these equations monthly and annual load estimates for this site will be determined.

3.3 Sample Collection Procedure

Two identical plastic buckets were purchased and used to collect the samples. These buckets are approximately 1.5 gallon capacity with a pouring spout. A rope was tied to the handle so the bucket could be lowered into the water below the center of the bridge. The bucket's spout assisted in pouring the river water into each of the prepared sample bottles to prevent any splashing.

Traveling to this location was also a very important consideration in selecting the Ponaganset River site. The approximate distance to the site is estimated at about 12 to 15 miles from the Providence Water Engineering Department office building. The shorter the distance required for travel to the collection site the better the response time for sampling prior to a storm event. Initial sampling at the beginning of a wet weather event is vitally important and always requires manual sampling. The use of automated sampling devices was considered for this project. However, due to the various types of samples being tested (Table 3.1), it would have required the purchase of four or five of these devices and would have added a greater expense to this project.

The site setup for dry weather sample collection was fairly simple to accomplish and required no temporary shelter, lighting, and five sample bottles, compared to fifty sample bottles used in wet weather. During dry weather sampling one set of constituents, which consisted of five sample bottles were collected on a bi-weekly basis. The approximate time frame required to prepare, collect, and process the samples for analysis was estimated to be two hours.

For each sample set collected at the Ponaganset River site there were five individual bottles. Later, non-detected constituents were eliminated which brought the set down to four individual bottles. During dry weather sample collection one set of samples was collected. During wet weather sampling a total of eight or more sets of samples were taken to fully cover the initial, peak, and tail end of the hydrograph. Table 3.1 indicates the attached form which was utilized in conjunction with the chain of custody form provided by Premier Laboratory for the samples collected at the site.

The proceeding section is intended to explain the types of constituents that were detected at the Ponaganset River site. These characteristics include potential sources of infiltration into the watershed and their effects on the human body when ingested in excess amounts. A brief description of primary and secondary water quality standards for constituents that were detected at the Ponaganset River site will be described.

Table 3.1: Chain of Custody Form Attachment

Contaminant	Results	DL	MCL	UNITS	Test Methodology	Preservation	Container	Bottle ID No.
Total Copper	**0.012**	0.010	1.3	mg/L	200.7 ICP - Inductively Coupled Plasma	HNO_3 or Nitric Acid	200 ml Plastic Bottle	1-A
Total Cadmium	ND	0.002	0.005	mg/L	200.7 ICP - Inductively Coupled Plasma	HNO_3 or Nitric Acid	200 ml Plastic Bottle	1-A
Total Zinc	**0.019**	0.010	5	mg/L	200.7 ICP - Inductively Coupled Plasma	HNO_3 or Nitric Acid	200 ml Plastic Bottle	1-A
Total Lead	ND	0.004	0.005	mg/L	200.7 ICP - Inductively Coupled Plasma	HNO_3 or Nitric Acid	200 ml Plastic Bottle	1-A
Total Aluminum	**0.120**	0.050	0.05 - 0.2	mg/L	200.7 ICP - Inductively Coupled Plasma	HNO_3 or Nitric Acid	200 ml Plastic Bottle	1-A
Total Nickel	ND	0.010	xl	mg/L	200.7 ICP - Inductively Coupled Plasma	HNO_3 or Nitric Acid	200 ml Plastic Bottle	1-A
Total Iron	**0.150**	0.050	0.3	mg/L	200.7 ICP - Inductively Coupled Plasma	HNO_3 or Nitric Acid	200 ml Plastic Bottle	1-A
Total Chromium	ND	0.010	0.1	mg/L	200.7 ICP - Inductively Coupled Plasma	HNO_3 or Nitric Acid	200 ml Plastic Bottle	1-A
Total Selenium	ND	0.001	0.05	mg/L	200.9 ICP - Inductively Coupled Plasma	HNO_3 or Nitric Acid	200 ml Plastic Bottle	1-A
Total Arsenic	ND	0.001	0.01	mg/L	200.9 ICP - Inductively Coupled Plasma	HNO_3 or Nitric Acid	200 ml Plastic Bottle	1-A
Total Beryllium	ND	0.001	0.004	mg/L	200.7 ICP - Inductively Coupled Plasma	HNO_3 or Nitric Acid	200 ml Plastic Bottle	1-A
Total Silver	ND	0.002	0.1	mg/L	200.7 ICP - Inductively Coupled Plasma	HNO_3 or Nitric Acid	200 ml Plastic Bottle	1-A
Total Mercury	ND	0.0002	0.002	mg/L	245.2 - Cold Vapor	HNO_3 or Nitric Acid	200 ml Plastic Bottle	1-A
Total Barium	**0.020**	0.010	2	mg/L	200.7 ICP - Inductively Coupled Plasma	HNO_3 or Nitric Acid	200 ml Plastic Bottle	1-A
Total Manganese	**0.035**	0.010	0.05	mg/L	200.7 ICP - Inductively Coupled Plasma	HNO_3 or Nitric Acid	200 ml Plastic Bottle	1-A
Total Vanadium	ND	0.010		mg/L	200.7 ICP - Inductively Coupled Plasma	HNO_3 or Nitric Acid	200 ml Plastic Bottle	1-A
Total Sodium	**12.0**	1.0	None	mg/L	200.7 ICP - Inductively Coupled Plasma	HNO_3 or Nitric Acid	200 ml Plastic Bottle	1-A
Acidity	ND	10.0	None	mg/L	305.1	Non-Preserved	1000 ml Plasic Bottle	2-A
Alkalinity	**1.2**	1.0	None	mg/L	SM 2320-B	Non-Preserved	1000 ml Plasic Bottle	2-A
Turbidity	**0.65**	0.10	None	NTU	SM 2130-B	Non-Preserved	1000 ml Plasic Bottle	2-A
Color	**25**		None	Color Units	SM 2120-B	Non-Preserved	1000 ml Plasic Bottle	2-A
Dissolved Orthophosphate	ND	0.020		mg/L	365.1	Non-Preserved	1000 ml Plasic Bottle	2-A
Nitrate (measured as Nitrogen)	ND	0.100	10	mg/L	SM 4500-NO_3 F	Non-Preserved	1000 ml Plasic Bottle	2-A
Chloride	**22.0**	2.0	250	mg/L	325.2	Non-Preserved	1000 ml Plasic Bottle	2-A
p H	**7.2**		6.5 - 8.5	pH Units	150.1 Electrometric	Non-Preserved	1000 ml Plasic Bottle	2-A
Total Suspended Solids (TSS)	ND	1.0	None	mg/L	160.2	Non-Preserved	1000 ml Plasic Bottle	2-A
Biological Oxygen Demand 5-Day	**<4**		None	mg/L	SM 5210-B	Non-Preserved	1000 ml Plasic Bottle	3-A
Total Phosphate	ND	0.020		mg/L	365.1	H^2SO_4 or Sulfuric Acid	500 ml Plastic Bottle	4-A
Ammonia	**0.110**	0.020	None	mg/L	350.1	H^2SO_4 or Sulfuric Acid	500 ml Plastic Bottle	4-A
Total Kjeldahl Nitrogen (TKN)	ND	0.500	ID	mg/L	351.1	H^2SO_4 or Sulfuric Acid	500 ml Plastic Bottle	4-A
Nitrate-Nitrite	ND	0.10		mg/L	SM 4500-NO_3 F	H^2SO_4 or Sulfuric Acid	500 ml Plastic Bottle	4-A
Total Coliform Bacteria (24 Hr.)	**Positive**		1/month	col/100mL	SM 9221 F - Membrane Filtration	(Sterile) Non-Preserved	100 ml Plastic Bottle	5-A
Escherichia Coli	**6**			col/100mL				

CHAPTER 4

4 SITE SPECIFIC WATER QUALITY CHARACTERISTICS WITH REFERENCE TO EPA GUIDELINES

4.1 Water Quality Standards

Though the years, there has been growing concern about the significance of trace elements in the environment. These elements are necessary for plant and animal growth in rivers such as the Ponaganset River. Excess exposure to trace elements, however, may disrupt the ecosystem and make the river unsuitable as a drinking water source. The United States Environmental Protection Agency (U.S. EPA) has developed standards to help protect the environment against harmful pollutants in natural waters. These standards are known as primary and secondary drinking water standards.

4.1.1 Primary Drinking Water Standards

"The National Primary Drinking Water Regulations (NPDWRs or primary standards) are legally enforceable standards that apply to public water systems. Primary standards protect public health by limiting the levels of contaminants in drinking water (U.S. EPA, 2005 NPDWR)". These standards pertain to the finished water from a treatment plant to the furthest point in the distribution system.

4.1.2 Secondary Drinking Water Standards

"National Secondary Drinking Water Regulations (NSDWRs or secondary standards (U.S. EPA, 2005 NSDWR) are non-enforceable guidelines regulating contaminants that may cause cosmetic effects (such as skin or tooth discoloration) or aesthetic effects (such as taste, odor, or color) in drinking water". Water utilities are not required to follow these standards although most, including the Providence Water Supply Board (PWSB), have stricter standards. The following list contains the suggested MCL (Maximum Contaminant Level) for nuisance chemicals that fall under the EPA's Secondary Drinking Water Standards.

Table 4.1: U.S EPA Suggested Secondary Maximum Contaminant Levels

Contaminant	**Secondary Standard**
Aluminum	0.05 to 0.20 mg/L
Chloride	250 mg/L
Color	15 (color units)
Copper	1.0 mg/L
Corrosivity	noncorrosive
Fluoride	2.0 mg/L
Foaming Agents	0.5 mg/L
Iron	0.3 mg/L
Manganese	0.05 mg/L
Odor	3 threshold odor number
pH	6.5-8.5
Silver	0.10 mg/L
Sulfate	250 mg/L
Total Dissolved Solids	500 mg/L
Zinc	5 mg/L

Source: (U.S. Environmental Protection Agency (2005) NSDWR)

4.2 Laboratory Selection

The samples for this project were tested by a certified laboratory (Premier Laboratory located in Dayville, Connecticut). The funding for testing was provided by Providence Water Supply Board (PWSB).

All testing followed the appropriate EPA standard methods. After the initial set of 32 samples was analyzed post wet weather event one, the data was reviewed. Constituents that were not detected were eliminated. The analytical data generated by the laboratory was compared to water quality standards to assess the conditions that existed at the site at the time of sampling. Results were correlated with discharge and precipitation data. The data was also used to identify in relation SMCL for corresponding constituents and identify constituent trends in both dry and wet weather conditions.

The original parameters evaluated in this analysis were selected based upon detected historical water quality data reviewed for this site with a total of 32 constituents (Table 4.2) tested at the Ponaganset River, only 15 (yellow highlighted Table 4.2) constituents were above detection limits. All other constituents were less than detectable trace amounts and were not considered any further.

Table 4.2: Summary of Detection Limits of Tested Constituents

Tested Constituents	Detection Limits	Units
Acidity	10	mg/L
Alkalinity	1.0	mg/L
Turbidity	0.10	NTU
Color		Color Units
pH		pH Units
Total Suspended Solids	1.0	mg/L
Total Coliform Bacteria	< 1	cfu/100 ml
Zinc	0.010	mg/L
Copper	0.010	mg/L
Barium	0.010	mg/L
Manganese		mg/L
Aluminum	0.050	mg/L
Iron	0.050	mg/L
Sodium	1.0	mg/L
Chloride	2.0	mg/L
Ammonia	0.020	mg/L
Dissolved Orthophosphate	0.020	mg/L
Nitrate (measured as Nitrogen)	0.100	mg/L
Nitrate-Nitrite		mg/L
Total Kjeldahl Nitrogen	0.500	mg/L
Total Phosphorous	0.020	mg/L
Biological Oxygen Demand		mg/L
Cadmium	0.002	mg/L
Lead	0.004	mg/L
Nickel	0.010	mg/L
Chromium	0.010	mg/L
Selenium	0.001	mg/L
Arsenic	0.001	mg/L
Beryllium	0.001	mg/L
Silver	0.002	mg/L
Mercury	0.0002	mg/L
Vanadium	0.010	mg/L

The fifteen parameters were detected under both dry and wet weather sampling during the period from April 2005 to September 2006 (17 months). The period was followed in order to eliminate accounting for leaf fall or snowmelt which influences the groundwater infiltration to the river. These constituents are a result of land use, geology, and nonpoint sources that are specific to the Ponaganset River in this region of the watershed.

4.3 Physical Characteristics of Water

4.3.1 Total Suspended Solids

Organic or inorganic particles that are carried by the runoff into receiving water are termed total suspended solids (TSS) (Chow, 1959). As discharge increases during wet weather conditions, particulates rise to the surface of the water. The suspension and settling of these materials are a function of the physical characteristics of the river channel, base flow, and rainfall characteristics. The suspension and resuspension of trace metals could cause greater environmental impacts with regard to the potential toxicity caused by trace metals. "The EPA has established acute and chronic concentrations for trace metals using relationship based on hardness" (Wright, Chaudhury, and Makam, 1994). Under dry weather conditions, the river's baseflow is influenced by groundwater drainage particles that tend to settle to the bottom of the river as sediment. This sediment includes eroded soil and other organic suspended solids which may require an oxygen demand on the surface water. In addition, the transport of sediment will eventually deposit into reservoirs, which over time will add significantly to the dead storage and reduce its useful life.

4.3.2 Turbidity

Turbidity is a measure of the optical characteristic that causes the light to be scattered and absorbed, rather than transmitted, with no change in direction through the sample. The amount of turbidity in the water is caused by the suspended and colloidal matter such as clay, silt, finely divided organic and inorganic matter, plankton, and other microscopic organisms (Clesceri, Greenberg, and Eaton, 1998). Some of these particulates may mask the screening for pathogenic microorganisms. Hazardous materials such as pesticides or heavy metals have the potential to be absorbed on suspended particulate matter. In water distribution systems the presence of turbidity may cause a decrease in the efficiency of the disinfection processes.

4.3.3 Color

The color of water is measured by PWSB using the method known as the platinum cobalt units or the tannin scale. The aesthetic property of water plays a role in a human's desire to drink, swim, bathe, or clean with it. The clearer the water, the more desirable it becomes to utilize it. Factors that affect the color in rivers are dissolved organic material from decaying vegetation, some types of species of organic matter, and excess formations of algae. Additionally, the presence of iron and manganese also influences the color of the water. The presence of color may make the water appear objectionable and may require treatment.

4.4 Chemical Characteristics of Water

4.4.1 pH

The pH level is a measure of the acidity or alkalinity of a water sample. The symbol pH stands for potential for hydrogen and equals the negative log of the H^+. The pH of water, on a scale of 0 to 14, is a measure of the free hydrogen ion concentration. Water contains both H+ ions and OH- ions. Pure distilled water contains equal number of H+ and OH- ions and is considered neutral (at pH 7), neither basic nor acidic. If water contains more H+ than OH- ions the water is considered acidic with a pH less than 7. If the water contains more OH- ions than H+ ions, the water is considered basic with a pH greater than 7 (U.S. Environmental Protection Agency, 2006 *Rivers and Streams*). Under the secondary maximum contaminant level (SMCL) standards the pH should be in the range of 6.5 to 8.5 units. The lead and copper rule requires pH adjustments to approximately 8.0 to 8.5 after filtration. PWSB has practiced pH adjustments of approximately 10.0 at the effluent of the treatment plant as means of corrosion protection to the distribution system for the past ten years. The laboratory has indicated that at furthest points of the distribution system that pH is approximately 9.5 to 9.6.

The pH of the water strongly influences the mobility of heavy metals in aqueous environments. Metal behavior in aquatic rivers is somewhat similar to that outside a water body. Sediment found on the streambed has the same characteristics that are associated in the normal soil environment. The results of this phenomena causes heavy metals to be sequestered at the bottom of the riverbed, while some become dissolved. The pH becomes the master variable in the whole process. In acidic like conditions, the H+ ions occupy most of the negatively charged surfaces of clay and organic material, although little room is left to bind metals which will remain in the soluble phase (Fairfax County Virginia, 2009). The aquatic organisms will be affected more due to extended contact with soluble metals.

4.4.2 Alkalinity

Alkalinity is an important measurement of the river's ability to neutralize acid rain, acid mine drainage, or wastewater. If the water in the river has a low alkalinity, it is prone to rapid changes in the pH level, although if it is high, it is able to resist major shifts in pH. Alkalinity not only helps regulate the pH of a water body, but also the metal content. Bicarbonate and carbonate ions in water can remove toxic metals (such as lead, arsenic, and cadmium) by precipitating the metals out of solution. (U.S. Environmental Protection Agency, 2006 Rivers and Streams *Total Alkalinity Status and Trends*)

4.4.3 Acidity

The acidity levels of water are directly linked to "Acid Rain" or pollutant rainfall. Atmospheric water vapor reacts with carbon dioxide (CO_2) and sulfur dioxide (SO_2), to form weak acids, resulting in a pH ranging from 4.5 to 5.6. In areas of high industrialization, the combustion of fossil fuels such as oil and coal emit sulfur dioxide (SO_2) and nitrogen oxides (NOx) in the atmosphere. Further transformation of these pollutants into gases such as sulfuric acid (H_2SO_4) and nitric acid (HNO_3) cause further elevated levels of acidity in the water. From concentrations observed at the site values appear to be higher than the historical average for this region.

4.4.4 Chlorides

Chlorides are is not harmful to humans unless consumed in excess in the form of sodium chloride or table salt, which could cause high blood pressure from extensive use over a long period of time. The taste of sodium chloride may be apparent at levels of 250 mg/L and magnesium or calcium chloride at 1000 mg/L.

Chloride may be introduced into river systems through rocks containing chlorides, agricultural runoff, and road salting during the winter months. Concentrations of chloride observed at the site were identified historically and were observed throughout this analysis during dry and wet weather conditions at the site and had the largest concentrations and loads of all the constituents.

4.5 Metal Characteristics

Trace metals that were detected at the Ponaganset River site included: barium, zinc, manganese, copper, aluminum, sodium, and iron. These constituents are considered inorganic and are primarily influenced by non-point sources that exist in this basin. The impact of these pollutants on the water quality may influence the ecosystem, and possibly render a body of water useless for long periods of time. The purpose of this section describes the types of detected metals that exist at the Ponaganset River site.

4.5.1 Barium

Barium levels may arise from the erosion of augen granite-gneiss with alkali-feldspar porphyroclasts from which it is derived. Low levels of barium on the Ponaganset River are likely to be from the weathering of these types of rocks along the rivers path. Increased levels of this constituent in amounts greater than the MCL of 2 mg/L may cause an increase in blood pressure.

4.5.2 Zinc

Agricultural runoff that contains pesticides or herbicides may also contain lead and zinc. Contributions of zinc may result from urban runoff in the form of tire wear from roadway systems. Zinc is also widely used in the auto industry as a protective coating for iron and steel. Galvanized pipe is also used in water distribution systems.

4.5.3 Manganese

Manganese is a common compound that can be found all over the world. In water distribution systems, it is noticed as a black color. This may cause stains on washed clothing and give beverages a medicine like taste.

4.5.4 Copper

Copper is a common metal found in roadway runoff from bearing wear, moving engine parts, and brake dust. Sources of copper indicate the erosion of natural deposits in raw surface water systems and corrosion of household plumbing systems contribute to elevated copper levels in effluent treated distribution systems. The MCL of copper is 1.3 mg/L. Excess of levels of 1.3 mg/L have the potential to cause gastrointestinal disease from short-term exposure and liver or kidney disease from chronic exposure.

4.5.5 Aluminum

Traces of aluminum found on the Ponaganset River are likely due to the erosion of natural deposits along the rivers path. Other potential sources may include rusting of vehicle body frames being washed into the river from roadways.

4.5.6 Sodium

Many people associate salty water with oceans or salt lakes although, all water includes some salt. High concentrations of sodium in river systems could be due to road salting during the spring snowmelt and areas where crop irrigation is used. Crop irrigation often picks up salt as it passes through the soil and returns back to the river. Excess sodium concentrations in rivers have the potential to affect the crop's soil if river water is used for irrigation. Sodium levels usually tend to increase during the winter and early spring months during wet weather condition due to roadway runoff from salting practices. Additional studies such as Runge and Wright, 1989 as well as Nimiroski and Waldron, 2002 have investigated sodium loads that contribute to the Scituate Reservoir based upon the number of roadway systems, surface area, and estimated amount of salt used on state and local roadways.

4.5.7 Iron

Possible contributions of iron entering into the river system occur from rusting automobile body frame or any type of rusting metal. In addition, iron can be released in small quantities by rock weathering. Iron and other trace metals have a low solubility so they bond to clay particles, which exist in large quantities in the soil. Small amounts of iron are necessary for plant, animal, and human health. Iron also releases a brownish color to the water which makes it unpleasant to look at, bathe in, or drink.

4.6 Bacterial Characteristics

4.6.1 Total Coliform Bacteria

Coliform consists of two groups: total coliform and fecal coliform. Regulations established by the U.S. EPA on June 19, 1989 set the maximum contaminant levels (MCL) for coliform based upon the presence or absence of Coliform rather than bacterial density. In larger systems such as the Scituate Reservoir Complex regulations require that if more than 40 samples per month are taken, they cannot have more than 5 percent positive results for the presence of coliform bacteria. From discussions with the PWSB laboratory total coliform bacteria typically increases at warmer water temperatures (August, September, and October). Total coliform bacteria concentrations can be influenced by weather conditions, high nutrient levels, and possible leaching of septic systems.

The EPA has four approved analytical methods for testing coliforms which are listed as follows:

1. Membrane Filtration Technique
2. Multiple-Tube Fermentation Technique
3. Minimal Media ONPG-MUG Test (colilert system) (MMO-MUG)
4. Presence-Absence Coliform Test

Premier Laboratory used the "Membrane Filtration Technique" for samples tested under both dry and wet weather conditions. All of the four approved testing methods require a 100 ml sample. The sample bottle must be sterilized prior to use and caution has to be taken when samples are collected to avoid any external contamination.

CHAPTER 5

5 DRY WEATHER ANALYSIS

5.1 Project Overview

At the beginning of this analysis, available historic water quality data was gathered and reviewed to determine the type of water quality data existing for the Scituate Reservoir Watershed. After extensive research into historic water quality records provided by PWSB, along with precipitation and discharge records provided by USGS, the Ponaganset River site was selected for this project. This project was intended to identify characteristic properties associated with wet and dry weather conditions that exist at the Ponaganset River site. Loads were determined for both wet and dry weather conditions for data gathered for this report. This study is the first wet weather study that has been conducted in the Scituate Reservoir Watershed.

5.2 Overview of Water Sample Collection Methodology

The Ponaganset River site was inspected to determine where the water samples should be collected prior to the first dry weather water sample collection. The objective was to identify and mark the exact cross section where the samples will be collected. From field observations it was determined that water samples have to be collected at the center of the bridge which allows for thorough mixing of the samples. Rainfall and discharge data was obtained using real-time fifteen-minute interval recording equipment at Ponaganset River site before, during, and after this investigation.

The objective during sample collection was to provide the most accurate representation of the water at the Ponaganset River site. Prior to gathering the analysis sample, all sampling equipment was rinsed with river water three times to assure that the river water collected was representative. The sample was obtained at the downstream side of the wooden bridge at Rams Tail Road (Figure 2.7). The collected water was distributed into five sample bottles provided by the laboratory shown in Table 5.1:

Table 5.1: Sample Preservation

Constituent	DL	MCL	Units	Preservation	Bottle Size
Copper	0.010	1.3	mg/L	HNO_3 or Nitric Acid	200 mL
Zinc	0.010	5	mg/L	HNO_3 or Nitric Acid	200 mL
Lead	0.004	0.005	mg/L	HNO_3 or Nitric Acid	200 mL
Aluminum	0.050	0.05-0.20	mg/L	HNO_3 or Nitric Acid	200 mL
Iron	0.050	0.3	mg/L	HNO_3 or Nitric Acid	200 mL
Chromium	0.010	0.1	mg/L	HNO_3 or Nitric Acid	200 mL
Barium	0.010	2	mg/L	HNO_3 or Nitric Acid	200 mL
Magnesium	0.010	0.05	mg/L	HNO_3 or Nitric Acid	200 mL
Sodium	1.0	None	mg/L	HNO_3 or Nitric Acid	200 mL
Acidity	10.0	None	mg/L	Non-Preserved	1000 mL
Alkalinity	1.0	None	mg/L	Non-Preserved	1000 mL
Turbidity	0.10	None	NTU	Non-Preserved	1000 mL
Color		None	Color Units	Non-Preserved	1000 mL
Dissolved Orthophosphate	0.020		mg/L	Non-Preserved	1000 mL
Nitrate (measured as Nitrogen)	0.100	10	mg/L	Non-Preserved	1000 mL
Chloride	2.0	250	mg/L	Non-Preserved	1000 mL
pH		6.5-8.5	pH Units	Non-Preserved	1000 mL
Total Suspended Solids (TSS)	1.0	None	mg/L	Non-Preserved	1000 mL
Biological Oxygen Demand 5-Day		None	mg/L	Non-Preserved	1000 mL
Total Phosphate	0.020		mg/L	H_2SO_4 or Sulfuric Acid	500 mL
Ammonia	0.020	None	mg/L	H_2SO_4 or Sulfuric Acid	500 mL
Total Kjeldahl Nitrogen	0.500		mg/L	H_2SO_4 or Sulfuric Acid	500 mL
Nitrate-Nitrite	0.10		mg/L	H_2SO_4 or Sulfuric Acid	500 mL
Total Coliform Bacteria (24 Hr.)		>5% out of 40 Samples	cfu/100 mL	(Sterile) Non-Preserved	100 mL

(Source: Clesceri, Greenberg, and Eaton, 1998)

5.3 Water Sample Collected Criteria

A total of twelve dry weather samples were collected at the Ponaganset River site for this project. During dry weather conditions samples were collected at a frequency of approximately every other week or biweekly during the period of April 15, 2005 to July 27, 2005 for dry weather samples identified in this report as numbers one (1) through eight (8). Dry weather samples nine (9) through twelve (12) were collected just prior to the onset of wet weather conditions. The twelfth dry weather sample collected for this report was collected in an attempt to capture a fourth storm event which did not meet the project criteria of 0.1 in of total precipitation.

Adjustments were made to the frequency of sampling based upon the weather conditions. The storm events that were selected for wet weather collection required the following criteria:

- Collection of three (3) or more wet weather events
- Precipitation totals greater than 0.1 inches
- Antecedent dry period of at least two (2) days
- Samples collected between April through September

During wet weather sampling, adjustments were made to the frequency between sampling based on the storm characteristics. If the storm was projected to last for an extended period of time with consistent rainfall amounts, samples were collected approximately every four hours. If a shorter more intense storm was expected, a frequency of every two to three hours would be ideal for samples collected at this site. To assure that accurate results were received by the laboratory, one duplicate sample set was collected and tested to ensure consistently accurate results. In addition, confidence levels will be determined in the conclusion of this investigation.

5.4 Laboratory Analysis

Premier Laboratory, located in Dayville, Connecticut conducted water sample analyses for this project. The laboratory was commissioned to pickup biweekly water samples during the collection of dry weather samples and multiple sample pickups during collection of wet weather events. The coordination efforts with the laboratory and the investigator were crucial during wet weather collection because these samples required various holding times.

The samples were transported to the laboratory in a chilled cooler filled with ice and or ice packs. Each sample bottle was labeled with a permanent marker and a numbering system for the bottles was determined prior to the initial sampling. For simplicity, labels were preprinted. Each bottle was labeled with the sample number, date, and time just prior to collecting the sample. In addition, a spreadsheet was prepared with the bottle number I.D. that corresponded to the sample bottle. The laboratory also requires a chain of custody form. The data received after testing was reviewed for consistency with historic sample results. The testing methods used by Premier Laboratory for constituents detected at the site are identified in Table 5.2:

Table 5.2: Selected Constituent Test Methodology

[redacted]ent	Methodology
Acidity	305.1
Chloride	SM4500
Color	SM2120B
Barium	200.7 ICP
Zinc	200.7 ICP
Manganese	200.7 ICP
Copper	200.7 ICP
Aluminum	200.7 ICP
Total Suspended Solids (TSS)	160.2
Alkalinity	SM2320B
Total Coliform Bacteria	SM-9222B
Sodium	200.7 ICP
Iron	200.7 ICP
pH in water	150.1
Turbidity	SM2130B

(Source: Premier Laboratory, 2005)

5.5 Dry Weather Sources that Influence the Water Quality

During dry weather conditions, point sources and groundwater conditions determine the river's water quality. Point sources are sources of pollution that can be traced back to a single source of origin. The base flow conditions during dry weather condition at the Ponaganset River identify discharge ranges between 0.98 to 34 cfs. These two components influence the water quality by means of rock weathering, plant decay, climate, and hydrology. The process of how some of these factors affect the water is briefly described below as follows:

- **Rock Weathering**

Some types of rocks contain minerals that are extremely soluble, while others are very resistant to chemical weathering. This weathering process typically generates in the form of solid residue that accumulates as a layer of soil on the bottom of the river bed. The bedrock geology in the Scituate Reservoir Watershed consists of primarily Devonian and late Proterozoic igneous and metamorphic rock. In the upper northern and western region are composed of primary Granite and gneiss of the Esmond igneous suite underlie this portion of the Scituate Reservoir basin. Constituents such as sodium and barium maybe introduced by the weathering of feldspars contained in metamorphic and igneous rock formations in the Scituate watershed. The breakdown of these rock formations occurs from the aqueous chemistry from small trace amount of carbonic (H_2CO_3), as well as hydrochloric and sulfuric acids in the river water which is discussed further in Section 7.2. Previous investigations by USGS have indicated that geologic weathering contributed approximately 11 percent of the sodium, but probably was not a major source of chloride (Nimroski and Waldron, 2002).

- **Plant Decay**

The process of decomposition of plant material influences the chemical characteristics of the water. This process generates organic acids and can form soluble complexes with metals such as zinc.

- **Climate and Hydrology**

Climate and hydrology are other factors that influence the rivers water quality. Previous reports published by USGS have indicated a mean annual temperature of 9.06 °C based on 19 years of record from the National Weather Service station in North Foster, Rhode Island (Breault, Waldron, Barlow, and Dickerman, 2000). The range of water temperatures observed for the analysis ranged from approximately 10.32 °C to 26.19 °C which was recorded from the analysis site between April through September 2005 and 2006. Deep, stagnant groundwater bodies develop high concentrations of metals, especially in arid areas where recharge rates are low. In wet regions, groundwater is recharged and flushed out at faster rates and for the same geologic conditions tends to be less concentrated. The geologic, climatic, and hydrologic environment, therefore, control the amount and the type of minerals in solution (Dunne and Leopold, 1978).

5.6 Dry Weather Results

The first set of dry weather results (DWR) received by the laboratory revealed that out of the 32 analyzed, only 16 were detectable. Samples shown in Table 5.3 identify the 16 parameters that were detected at during dry weather conditions at the Ponaganset River site. The photo shown in Figure 5.1 illustrates the location point where the samples where collected at the site.

Figure 5.1: Photo of Ponaganset River - Sample Collection Point (2006)

The first dry weather (DW 1) sample was collected at the site on April 15, 2005 at 12:30 pm at which time the base flow at the river was 25.5 cfs. Results from Premier Laboratory were reviewed approximately one to two weeks after DW 1 was collected. Prior to collection and analysis of the second set of dry weather samples, it was decided to duplicate testing for the initial 32 samples. This was done to verify that all the constituents measured would reappear as detectable or non-detectable and not just a coincidence. The second dry weather collection revealed 3 mg/L of total suspended solids (TSS) for which the first dry weather sample set did not detect. TSS was detected a total of 8 out of 12 samples and concentrations ranged from 1 to 6 mg/L and averaged 3.6 mg/L.

Aluminum was detected on the DW 1, 3, 6, 7, 9, 10, 11, and 12 (or 8 out of 12 samples). Concentrations of aluminum ranged from 0.044 to 0.120 mg/L and averaged 0.090 mg/L. for the 8 dry weather samples (Table 5.3). The average acidity observed was 6.43 mg/L during dry weather for only 10 out 12 samples tested. Alkalinity was detected on DW 1, 4, 5, 9, 11, and 12 (or 6 out of 12 samples) Total copper was initially detected on DW 1 and 2, and then was non-detectable for the remaining 10 samples. Total copper was detected at discharge rates greater than 25.5 cfs during dry weather conditions. Total coliform bacteria was detected in 11 out of 12 samples. Table 5.3 identifies the dry weather data results of the constituents that were observed at the site, and Figure 5.2 through Figure 5.9, which describe the observed metals and total coliform bacteria concentrations graphically, with secondary maximum contaminant level (SMCL) which are non-enforceable regulations related to the maximum allowable concentrations for raw water supply before it is treated. In addition, Figure 5.3, 5.6, and 5.7 also identify historical average concentrations for zinc, barium, and manganese based upon previous testing by Premier Laboratory. The historical average of zinc (0.019 mg/L) was based upon 3 samples while averages of barium (0.019 mg/L) and manganese (0.225 mg/L) were based upon 5 independent samples between 2002 and 2005 shown in Appendix E. The average historic manganese was high due to one extremely high concentration observed on 9/14/2005 at 0.960 mg/L at a very low flow rate of 0.08 cfs in the river. The collection of dry weather samples for this analysis were ceased in July 2005 due to drought like conditions so, in September 2005 concentrations of manganese were like due to sedimentation from the bottom of the river which resulted in a very high concentration. Historic samples were tested using the same test methodology as the analysis samples and fitting the dry weather criteria of having at least 2 days antecedent dry period.

Table 5.3: Dry Weather Results

Ponaganset River (Site 01115187) - DW Analysis Results

Date:		**4/15/2005**	**5/5/2005**	**5/19/2005**	**6/2/2005**	**6/15/2005**	**6/23/2005**	**7/13/2005**	**7/27/2005**	**5/2/2006**	**7/12/2006**	**9/19/2006**	**9/28/2006**				
Time:		**12:30 PM**	**5:15 PM**	**12:30 PM**	**12:30 PM**	**12:45 PM**	**12:45 PM**	**12:45 PM**	**12:45 PM**	**9:15 AM**	**1:15 PM**	**7:15 PM**	**7:30 PM**				
Sample No:		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**				
Flow (cfs)	**Units**	25.5	34	16	20.75	4.43	3.72	3.51	0.98	12	14	4.7	3.3				
Contaminant		**Results**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**	**Max.**	**Min.**	**Ave.**	**SD**
Total Copper	mg/L	**0.012**	**0.022**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**0.022**	**0.012**	**0.017**	**0.007**
Total Zinc	mg/L	**0.019**	**0.022**	**0.018**	**ND**	**0.016**	**0.045**	**0.340**	**ND**	**0.016**	**ND**	**ND**	**ND**	**0.340**	**0.016**	**0.068**	**0.120**
Total Aluminum	mg/L	**0.120**	**ND**	**0.110**	**ND**	**ND**	**0.110**	**0.110**	**ND**	**0.066**	**0.110**	**0.050**	**0.044**	**0.120**	**0.044**	**0.090**	**0.031**
Total Iron	mg/L	**0.150**	**0.250**	**0.360**	**0.250**	**0.800**	**0.560**	**0.540**	**0.710**	**0.130**	**0.370**	**0.380**	**0.300**	**0.800**	**0.130**	**0.400**	**0.212**
Total Barium	mg/L	**0.020**	**0.019**	**0.018**	**0.016**	**0.021**	**0.019**	**0.020**	**0.017**	**0.018**	**0.016**	**0.013**	**0.016**	**0.021**	**0.013**	**0.018**	**0.002**
Total Manganese	mg/L	**0.035**	**0.032**	**0.046**	**0.029**	**0.066**	**0.053**	**0.062**	**0.070**	**0.023**	**0.025**	**0.020**	**0.027**	**0.070**	**0.020**	**0.041**	**0.018**
Total Sodium	mg/L	**12.0**	**12.0**	**13.0**	**9.2**	**14.0**	**13.0**	**13.0**	**13.0**	**14.0**	**11.0**	**14.0**	**17.0**	**17.0**	**9.2**	**12.9**	**1.9**
Acidity	mg/L	**8.5**	**7.0**	**9.0**	**7.0**	**5.0**	**3.0**	**3.0**	**4.0**	**3.8**	**14.0**	**ND**	**ND**	**14.0**	**3.0**	**6.4**	**4.0**
Alkalinity	mg/L	**1.2**	**ND**	**ND**	**3.0**	**2.5**	**ND**	**ND**	**ND**	**22.0**	**ND**	**2.7**	**2.7**	**22.0**	**1.2**	**5.7**	**8.0**
Turbidity	NTU	**0.65**	**0.40**	**0.70**	**0.70**	**1.50**	**0.90**	**0.80**	**0.90**	**0.55**	**1.40**	**0.60**	**0.57**	**1.50**	**0.40**	**0.81**	**0.33**
Color	Color Units	**25**	**40**	**50**	**35**	**55**	**40**	**50**	**60**	**30**	**60**	**30**	**40**	**60**	**25**	**43**	**12**
Chloride	mg/L	**22**	**20**	**22**	**20**	**23**	**23**	**26**	**24**	**24**	**18**	**26**	**27**	**27**	**18**	**23**	**3**
p H		**7.2**	**7.6**	**7.4**	**7.6**	**6.2**	**6.5**	**6.7**	**7.0**	**6.6**	**6.1**	**6.8**	**7.0**	**7.6**	**6.1**	**6.9**	**0.5**
Total Suspended Solids (TSS)	mg/L	**ND**	**3.0**	**ND**	**2.0**	**1.0**	**ND**	**3.0**	**5.0**	**ND**	**6.0**	**5.7**	**3.0**	**6.0**	**1.0**	**3.6**	**1.8**
Ammonia	mg/L	**0.110**	**0.120**	**0.087**	**0.092**	**0.080**	**0.069**	**0.037**	**NT**	**NT**	**NT**	**NT**	**NT**				
Total Coliform Bacteria	cfu/100 mL	**6**	**35**	**19**	**210**	**80**	**160**	**200**	**20**	**70**	**TNTC**	**180**	**200**	**210**	**6**	**107**	**83**

Note:

ND = Non-Detectable

TNTC = To Numerous To Count

NT = Not Tested

Max., Min., Ave., SD = Standard Devation were determined based upon the number of results for each constituent.

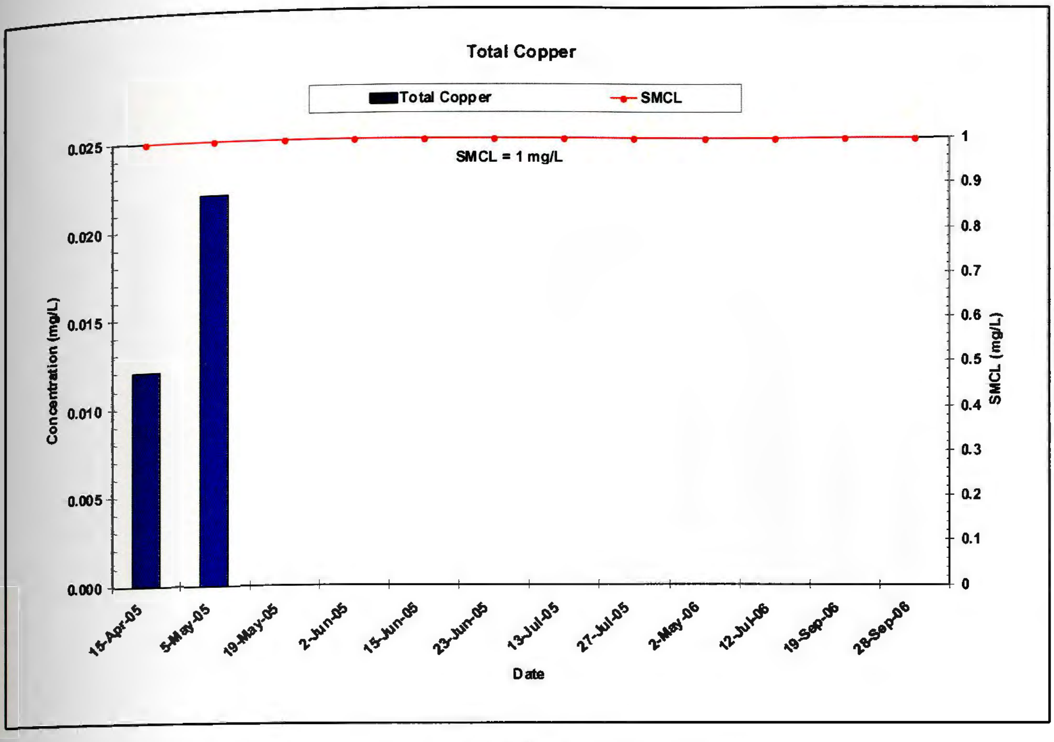


Figure 5.2: Copper Concentrations Dry Weather Sampling

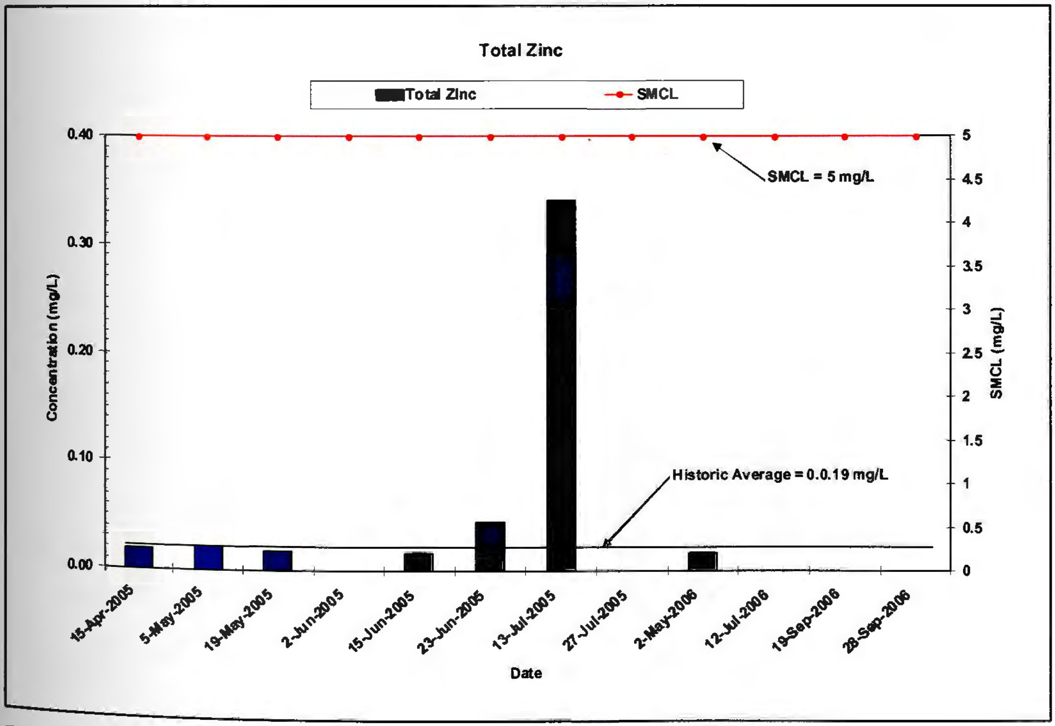


Figure 5.3: Zinc Concentrations Dry Weather Sampling

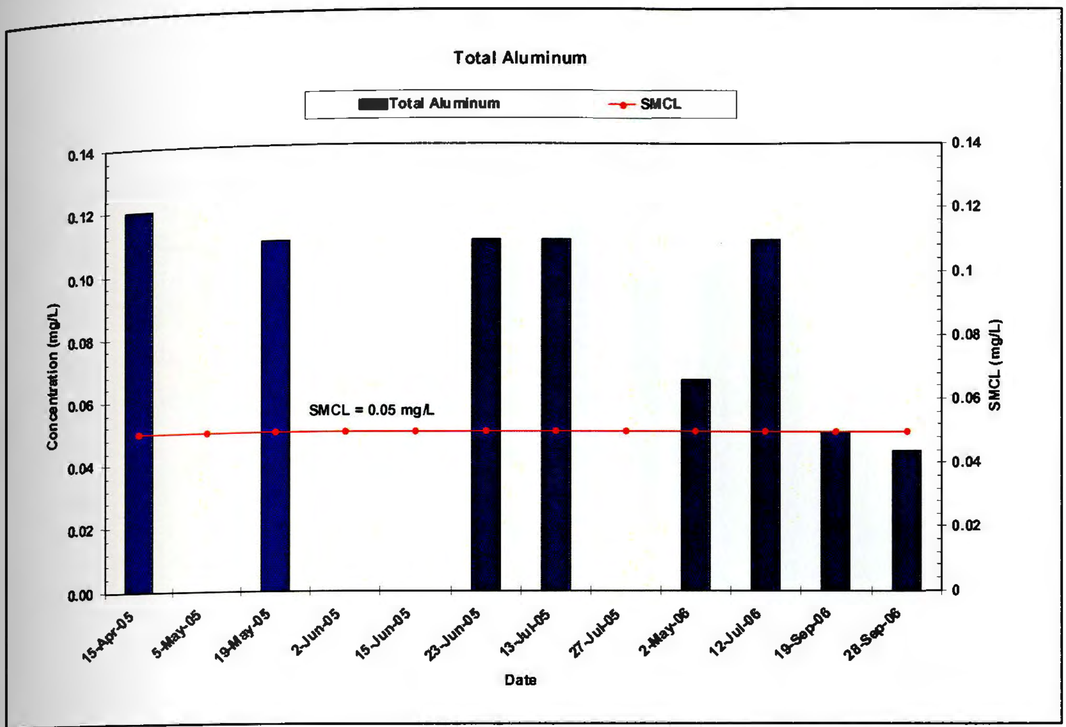


Figure 5.4: Aluminum Concentrations Dry Weather Sampling

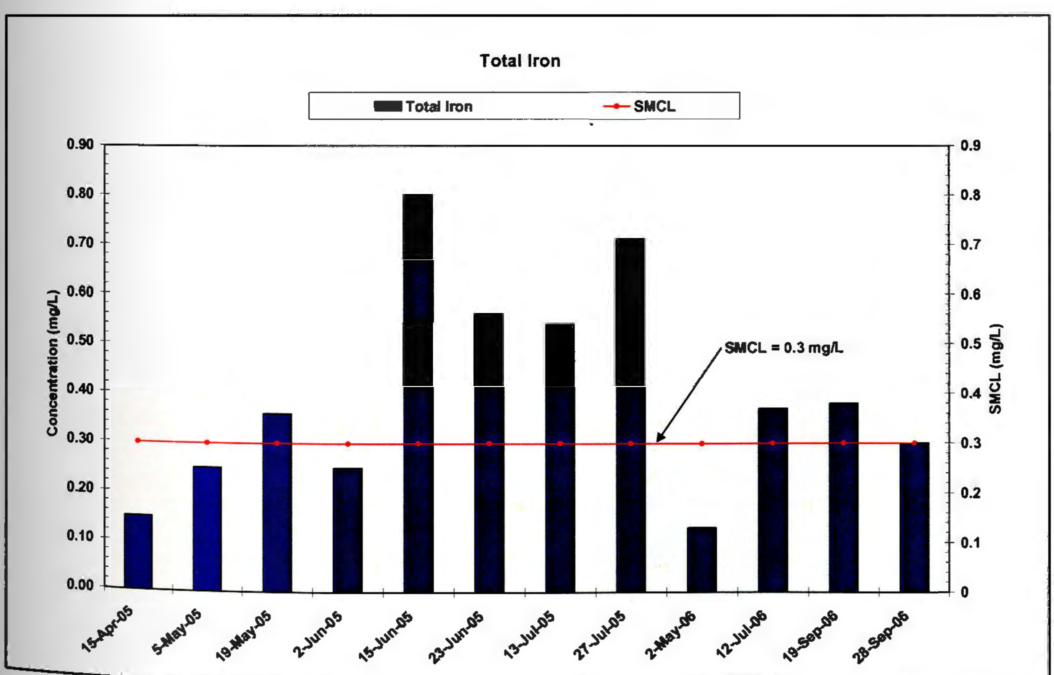


Figure 5.5: Iron Concentrations Dry Weather Sampling

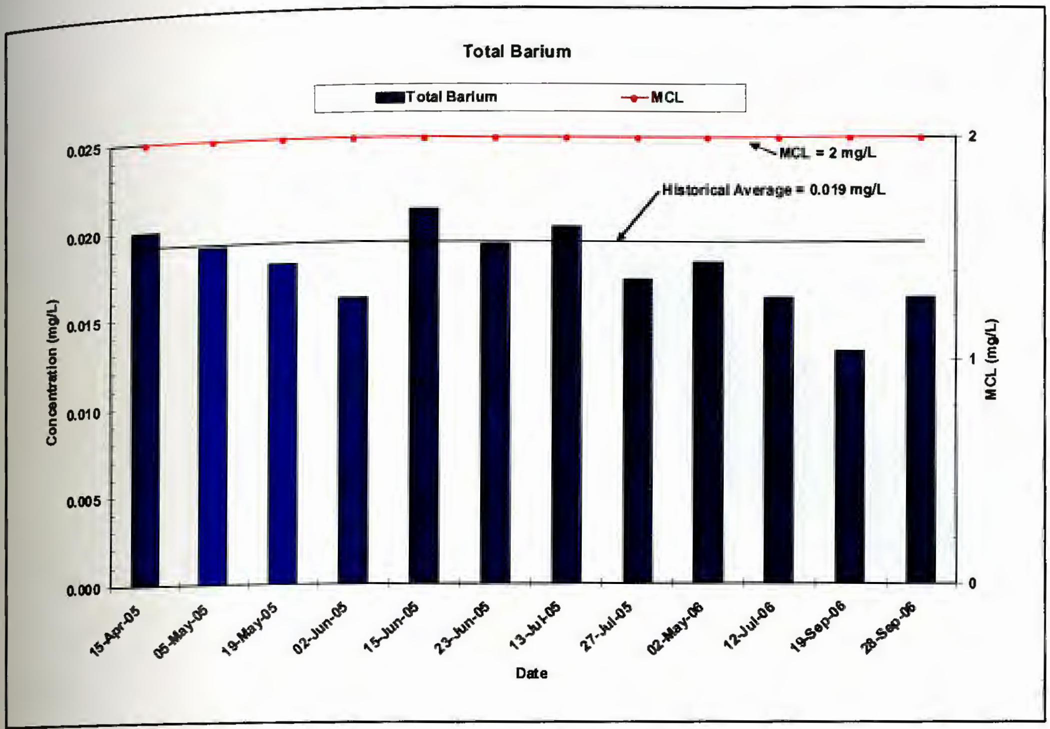


Figure 5.6: Barium Concentrations Dry Weather Sampling

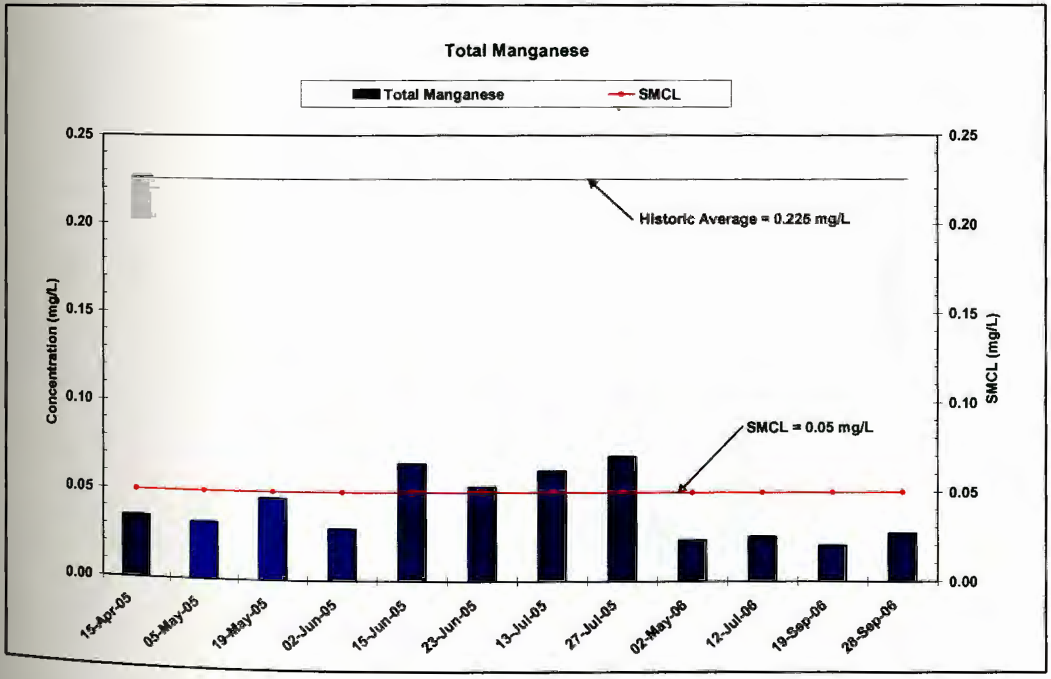


Figure 5.7: Manganese Concentrations Dry Weather Sampling

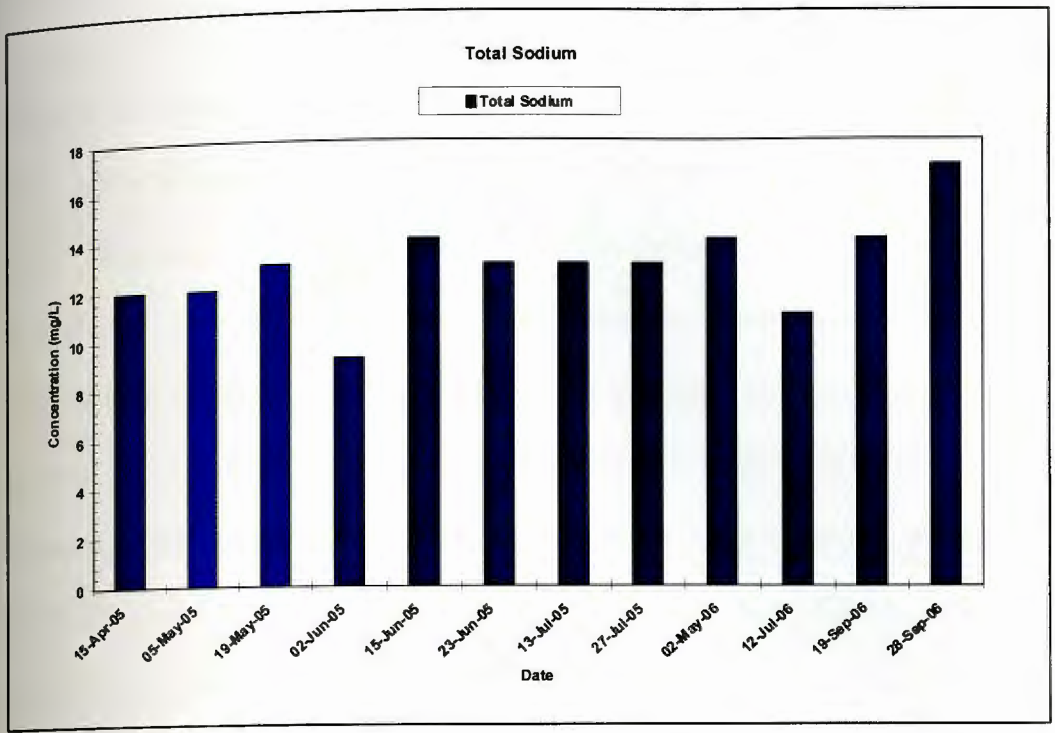


Figure 5.8: Sodium Concentrations Dry Weather Sampling

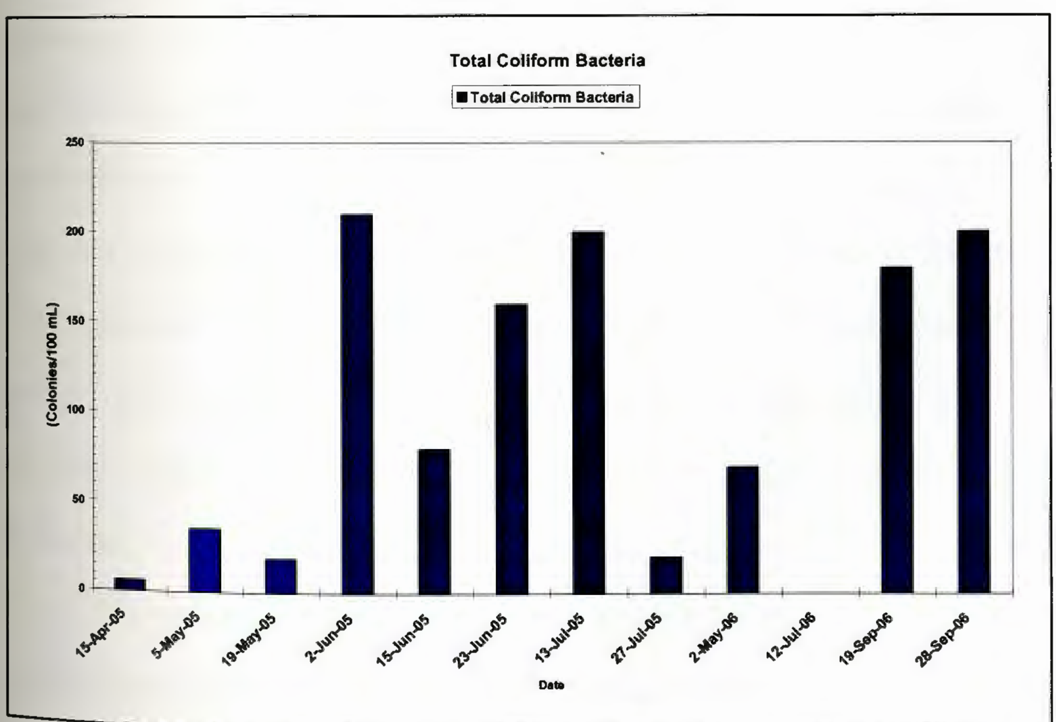


Figure 5.9: Total Coliform Bacteria Dry Weather Sampling

CHAPTER 6

6 WET WEATHER ANALYSES

6.1 Wet Weather Forecasting and Monitoring Criteria

Wet weather monitoring helps to provide a determination of the variations in pollutant loads under diverse weather conditions. River flows are higher in wet-weather causing temporary increases in pollutant loadings that fluctuate throughout the duration of the storm. These pollutant loads are the result of a re-suspension and reactivation of contaminants in the rivers sediment, which may affect the health of aquatic species. The significance of this effect is influenced by the amount, intensity, and duration of the storm.

The one primary goal associated with this project was to determine the wet weather characteristics at the Ponaganset River site. This involved accurate forecasting of weather conditions that would be suitable for field sampling. The criteria for wet weather sampling required two days of antecedent dry period, a minimum of 0.1 inches of total precipitation, and collection of enough samples to adequately cover the hydrograph. Weather forecasting sites such as local news web sites, weather underground, national weather service, and other sources were used to estimate the expected rainfall events. In addition, coordination of sample pickup from Premier Laboratory required that sample pick-ups be done on Monday through Friday during regular work hours to avoid excess project expenses.

The frequency of sampling under wet weather conditions was determined on site, based upon the projected forecast and the predicted response the river.

From previous research, discharge data indicated that in almost all cases the river returned to baseflow within forty eight hours.

If the projected storm extended for a period of time, perhaps one to two days, the samples would be taken at intervals of four hours dependent on the intensity of the storm. Storms of short duration, such as summer storms were considerably more difficult because tracking is difficult to due to uncertain movements, intensity, and short duration. Various attempts were made to sample during thunderstorms, although none were captured for use in this analysis.

During wet-weather, samples were collected at a frequency of every one to four hours, and post rainfall at a frequency of approximately eight to twelve hours apart for the last two sets of samples. This sample frequency was utilized for the Ponaganset River site based upon the small sub watershed drainage area characteristics.

6.2 Distinct Rainfall Characteristics

Rainfall is the driving force for the hydrologic cycle which controls our water supplies. By understanding the nature and characteristics of rainfall, determinations can be made on its effect in relation to runoff, infiltration, evapotranspiration, and annual yields. In this analysis the Ponaganset River site was utilized for its recording rain gauge which provides a record of accumulation as a function of time. Hence, allowing for the total precipitation, intensities, and duration to be determined for each of the three individual storm events described in this analysis, (Table 6.1) allowing for the determination of empirical equations employed for the analysis. These rainfall characteristics are briefly described below:

- **Total Rainfall**

  One of the most obvious characteristic of rainfall is the total amount of precipitation that falls during the course of the storm. This is an easy measure of determining the severity of the storm being described. The total rainfall amount often raises or lowers the amount of sediment transported in the river. During this analysis, three storms were captured with total precipitation amounts described in Table 6.1.

- **Intensity and Duration**

  Intensity and duration are typically inversely related. Usually, high intensity storms have a short duration, while low intensity storms have a longer duration. During storm event number one, the intensity was 0.18 in./hr. with a duration of 53 hours while the intensity of storm number three reached 0.24 in./hr. with a duration of only 5 hours (Table 6.1).

Table 6.1: Rainfall Characteristics

Description	Units	Storm I.D. # 1 5-2-06	2 7-12-06	3 9-19-06
Total Storm Duration	(hrs.)	53	20	5
Total Precipitation Duration	(hrs.)	13	3.75	2.75
Antecedent Dry Period	(days)	8	5	3
Total Precipitation (P_T)	(in.)	1.38	0.57	0.45
Peak Intensity	(in./hr.)	0.18	0.16	0.24
Peak Discharge ($Q_{Max.}$)	(cfs)	88	21	7.5
Initial Baseflow	(cfs)	10	13	4.2
Direct Runoff Volume (V)	(cf)	9160	910	775
Effective Precipitation (Pn)	(in.)	0.986	0.098	0.083
Time To Peak	(hrs.)	38.5	25	17.75

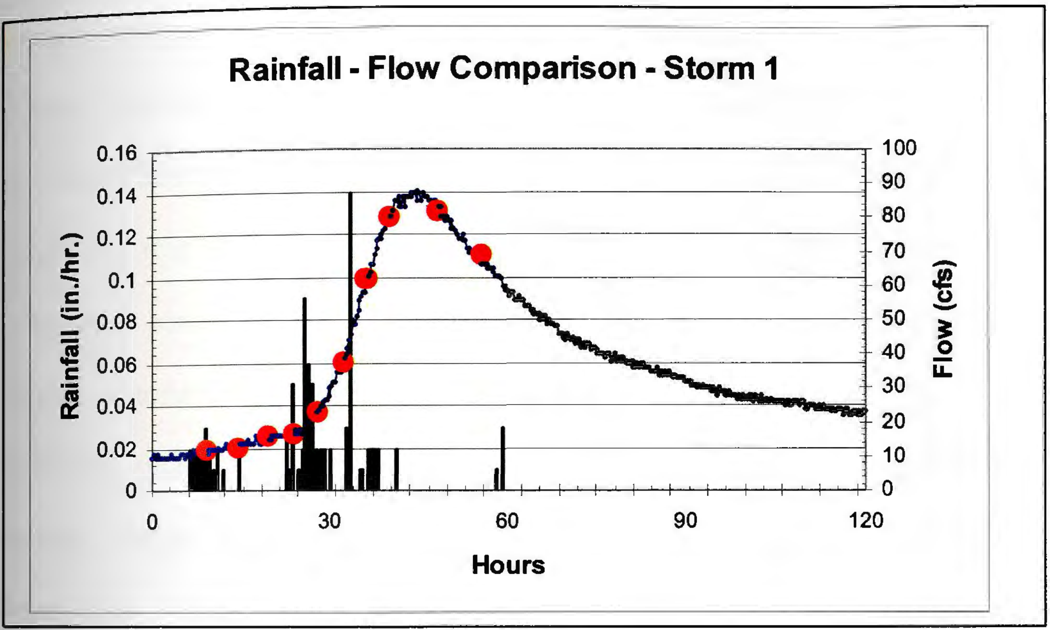
In addition to the characteristics described above, the rainfall distribution also affects the amount of runoff. The large scale areas such as the Scituate Reservoir's 92.8 square mile watershed is more susceptible to variations of runoff rather than the 14.4 square mile watershed around the Ponaganset River site 01115187 used in this analysis. During collection of wet weather, data observations were made on thunderstorms that moved through the area of Foster. Thunderstorms often change direction quickly, thus influencing the rainfalls distribution within the watershed and also affecting the runoff. In Table 6.1 rainfall characteristics for storms 1,2, and 3 indicate 71.45%, 17.19%, and 18.44 % of the rain that fell in this sub-basin entered the river in the form of runoff. Past studies commissioned by PWSB have indicated that approximately 50% of the rain that falls within the limits of the entire 92.8 square mile watershed is runoff and is stored in the five tributaries, which all flow into the Scituate Reservoir. In the case of this analysis, the Ponaganset river watershed is the most forested region which also largely influences the amount of runoff entering the river. Prior to the start of runoff the amount of rainfall required must satisfy infiltration demands, evaporation, interception, and surface storage. For each of the three storms observed at this site (storms 1, 2,and 3) required 0.39, 0.47, and 0.37 inch of total precipitation or an average of 0.41 inch to satisfy these requirements before runoff can occur. Once these requirements are satisfied, the runoff contributions can be used to determine factors that affect the transport of constituents that are distinct to the point measured on the river.

Rainfall characteristic phenomena can be used in an analysis of its own. The objective in this section is to briefly describe factors that are influenced by these rainfall traits. On previous studies conducted on the entire Scituate Reservoir Watershed attempts were made to determine if the arithmetic mean of the five rain gauges measured by PWSB is as accurate as the Thessian approach. The result of that study showed that both were equally as accurate when compared to long term historic results. In this analysis real-time rainfall, discharge, and water quality records were used to determine the pollutant loads for constituents identified consistently at the site for wet and dry weather conditions.

6.3 Storm 1 Characteristics

The first wet weather event began on May 2, 2006 at 6:30 AM and ended on May 4, 2006 at 11:30 AM (53 hours). This storm event had a rainfall total of

1.38 in., a peak intensity of 0.14 in./hr., and a maximum discharge rate of 88 cfs (Figure 6.1). This storm had the largest amount of rainfall out of the three collected for wet weather analysis. During the course of this storm a total of ten sets of samples were collected for 32 constituents analyzed during wet weather event one.



* The red circles indicate the time the sample was collected.

Figure 6.1: Rainfall – Flow Comparison – Storm 1: May 2, 2006

The results of testing for WW 1 indicate that out of the ten sets of samples collected throughout the storm, eleven constituents were detected consistently which are listed as follows: barium, zinc, manganese, aluminum, sodium, iron, turbidity, color, chloride, pH, and total coliform bacteria.

In addition, four of the constituents measured had partial records of concentrations found during WW 1 are listed as follows: copper, acidity, alkalinity, and total suspended solids.

All of the other sixteen constituents measured during WW 1 were non-detectable, as they were during DW 1. Ammonia was not tested during wet weather due to very low trace amounts found during dry weather samples 1 through 7. The intent of this analysis was geared to detected constituents that are particular to the Ponaganset River at site 01115187 during dry and wet weather conditions.

The results from the samples that were detected during WW 1 one showed various patterns of concentrations in relation to runoff from the river. Barium, sodium, chloride, and pH, levels appear to decrease during higher flows due to dilution. The results found that these measured samples were less than base flow conditions that were collected during dry weather. Concentrations of zinc illustrate a somewhat erratic response, although for the most part it tends to increase during higher flows. In addition, a number of detected constituents measured such as manganese, aluminum, iron, acidity, turbidity, and total coliform bacteria increased in concentration as the runoff increased on the Ponaganset River. Results of alkalinity and total suspended solids were inconclusive due to partial detection of the ten samples measured. Color did not change from 30 color units throughout the entire period of sampling.

Table 6.2: Wet Weather 1 Results

Wet Weather Event 1 - Precipitation Total = 1.38 in., Duration = 13 hrs.
Date: May 2, 3, & 4, 2006

Metal Samples

Bottle I.D.	Date	Time	Flow (cfs)	Barium (mg/L)	Zinc (mg/L)	Manganese (mg/L)	Copper (mg/L)	Aluminum (mg/L)	Sodium (mg/L)	Iron (mg/L)
1-A	5/2/2006	9:15 AM	12	0.018	0.016	0.023	ND	0.066	14	0.13
2-A	5/2/2006	2:45 PM	13	0.017	0.019	0.020	0.0017	0.061	14	0.12
3-A	5/2/2006	7:30 PM	15	0.016	0.016	0.018	0.0014	0.067	13	0.13
4-A	5/3/2006	12:00 AM	17	0.016	0.013	0.018	ND	0.068	14	0.12
5-A	5/3/2006	4:00 AM	23	0.017	0.022	0.020	0.0018	0.075	13	0.15
6-A	5/3/2006	8:30 AM	38	0.016	0.020	0.024	0.0011	0.091	11	0.19
7-A	5/3/2006	12:15 PM	62	0.016	0.025	0.032	0.0011	0.100	11	0.22
8-A	5/3/2006	4:00 PM	79	0.016	0.012	0.032	ND	0.120	10	0.16
9-A	5/4/2006	12:15 AM	82	0.016	0.024	0.027	ND	0.130	11	0.15
10-A	5/4/2006	8:00 AM	66	0.017	0.016	0.023	ND	0.130	11	0.14

Organic & Total Bacteria Samples

Bottle I.D.	Date	Time	Flow (cfs)	Acidity (mg/L)	Alkalinity (mg/L)	Turbidity (NTU	Color (Color Units)	Chloride (mg/L)	p H	TSS (mg/L)	T. Coliform (cfu/100mL)
1-B	5/2/2006	9:15 AM	12	3.8	22	0.55	30	24	6.60	ND	70
2-B	5/2/2006	2:45 PM	13	1.8	22	0.67	30	23	6.60	ND	20
3-B	5/2/2006	7:30 PM	15	ND	ND	0.69	30	22	6.50	6.0	10
4-B	5/3/2006	12:00 AM	17	6.6	ND	0.83	30	21	6.20	1.0	120
5-B	5/3/2006	4:00 AM	23	6.6	ND	1.10	30	22	6.20	ND	90
6-B	5/3/2006	8:30 AM	38	6.6	ND	1.30	30	19	6.20	1.0	100
7-B	5/3/2006	12:15 PM	62	9.6	ND	1.10	30	19	6.20	9.0	210
8-B	5/3/2006	4:00 PM	79	9.6	ND	1.00	30	19	6.20	ND	210
9-B	5/4/2006	12:15 AM	82	9.6	ND	0.75	30	19	6.20	ND	900
10-B	5/4/2006	8:00 AM	66	3.8	ND	0.51	30	20	5.90	6.0	190

6.4 Elimination of Non-Detected Samples

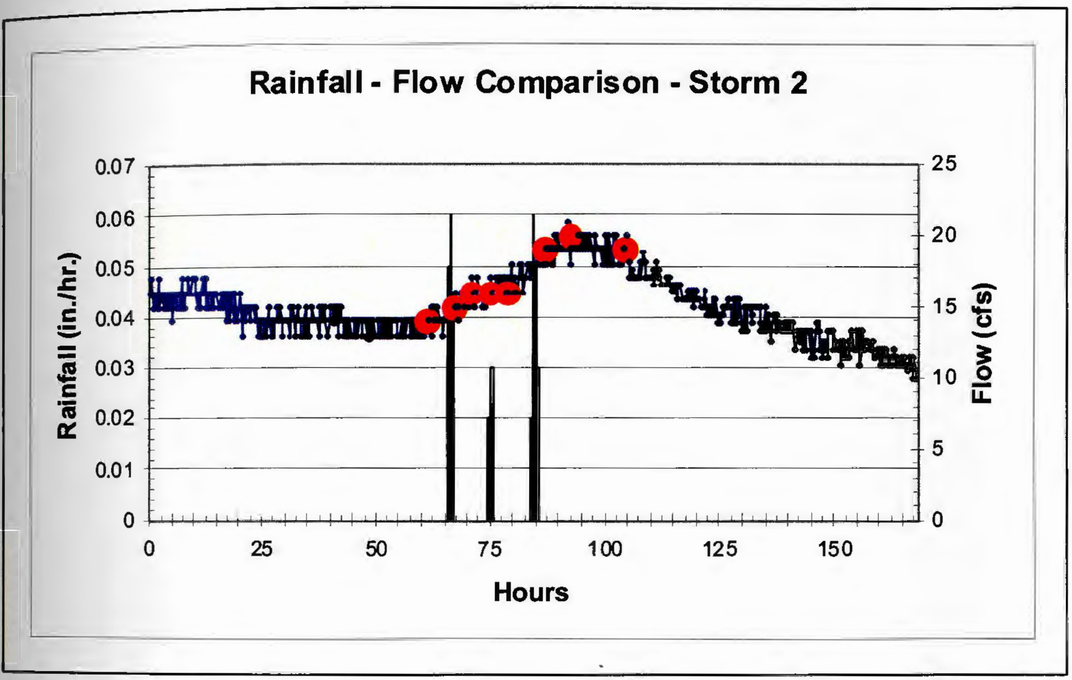
After the data from the first storm event was collected, the analysis results were reviewed for accuracy and consistency. The resulting data revealed out of 32 of the proposed samples analyzed only 15 were detected. If the proposed constituents did not appear in both dry and wet weather conditions then the sample was discarded for testing for the second storm event. There was a concern that some constituents could exist during other various size storm events. Parameters that were questioned included copper, alkalinity, and total suspended solids, which had partial records of concentrations found during WW 1. All of the other 12 detected parameters measured during the first storm event were detected in all 10 samples aside from one missing concentration out of ten for acidity.

Prior to the start of collection of samples for the second wet weather event a decision was made to test the fifteen parameters that indicated ten out of ten results that were above the specified detection limits. These parameters will be the basis for subsequent field collection of wet and dry water quality samples tested at the site.

6.5 Storm 2 Characteristics

The second storm event for this analysis began on July 12, 2006 which had a duration of 3.75 hrs., and total rainfall equivalent of 0.57 in.. During the course of this storm event a total of 9 sets of samples were collected at intervals of approximately four to six hours apart for the first 8 sets of samples, and approximately twelve hours apart for the 9th sample set. The resulting analytical data revealed that concentrations in the second storm event decreased in comparison to the first. The reason for this decrease in concentrations corresponds to the magnitude of the storm, and the antecedent dry period.

The second storm event revealed no traces of copper, zinc, and alkalinity for the nine samples taken during course of this storm event. Copper was found in dry weather samples one and two, although it was detected by the laboratory when flows in the Ponaganset River were measured at 25.5 cfs and 34 cfs, respectively. During the second storm event the rivers maximum discharge only reached to 21 cfs therefore, for copper to exist at this river, flows would have to be greater than 21 cfs and less than 25.5 cfs to be detected on this river where the samples were measured. Zinc, on the other hand appears to be detected in higher concentrations with higher ranges of flows (0.024 mg/L at 82 cfs in wet weather event one) and at minimal flow rates (0.340 mg/L at 3.51 cfs in dry weather sample number seven) at the site. Storm 2 showed 9 out of 9 results for concentrations of total suspended solids (TSS). The TSS levels may have been more apparent due to greater amounts of particulates floating at the rivers surface under small-scale rainfall conditions. The resulting data for TSS levels ranged from 1 to 11 mg/L but are not in direct correlation to discharge. Constituents such as barium, sodium, and chloride concentrations appeared relatively constant. The pH levels decreased from 6.10 to 4.70 with a difference of 1.4 (Table 6.3). Total coliform bacteria results were obtained for only four out of nine samples because testing methods used by the laboratory did not dilute the sample enough to determine bacteria levels in excess of 1000 colonies. Adjustments were made to correct the dilution methodology for the subsequent storm events.



* The red circles indicate the time the sample was collected.

Figure 6.2: Rainfall – Flow Comparison – Storm 2: July 12, 2006

The Ponaganset Rivers rainfall – flow characteristics in relation to when samples were collected during the second wet weather event are illustrated in Figure 6.2.

Table 6.3: Wet Weather 2 Results

Wet Weather Event 2 - Precipitation Total = 0.57 in., Duration = 3.75 hrs.
Date: July 12,13, & 14, 2006

Metal Samples

Bottle I.D.	Date	Time	Flow (cfs)	Barium (mg/L)	Zinc (mg/L)	Manganese (mg/L)	Copper (mg/L)	Aluminum (mg/L)	Sodium (mg/L)	Iron (mg/L)
1-A	7/12/2006	1:15 PM	14	0.016	ND	0.025	ND	0.110	11	0.37
2-A	7/12/2006	7:00 PM	15	0.015	ND	0.025	ND	0.100	11	0.39
3-A	7/12/2006	10:30 PM	16	0.015	ND	0.024	ND	0.100	10	0.41
4-A	7/13/2006	2:30 AM	16	0.015	ND	0.026	ND	0.093	10	0.42
5-A	7/13/2006	6:30 AM	16	0.015	ND	0.026	ND	0.100	10	0.45
6-A	7/13/2006	10:30 AM	17	0.015	ND	0.027	ND	0.099	10	0.43
7-A	7/13/2006	2:30 PM	19	0.016	ND	0.066	ND	0.120	10	0.43
8-A	7/13/2006	8:15 PM	20	0.016	ND	0.029	ND	0.140	10	0.49
9-A	7/14/2006	8:30 AM	19	0.016	ND	0.029	ND	0.140	10	0.51

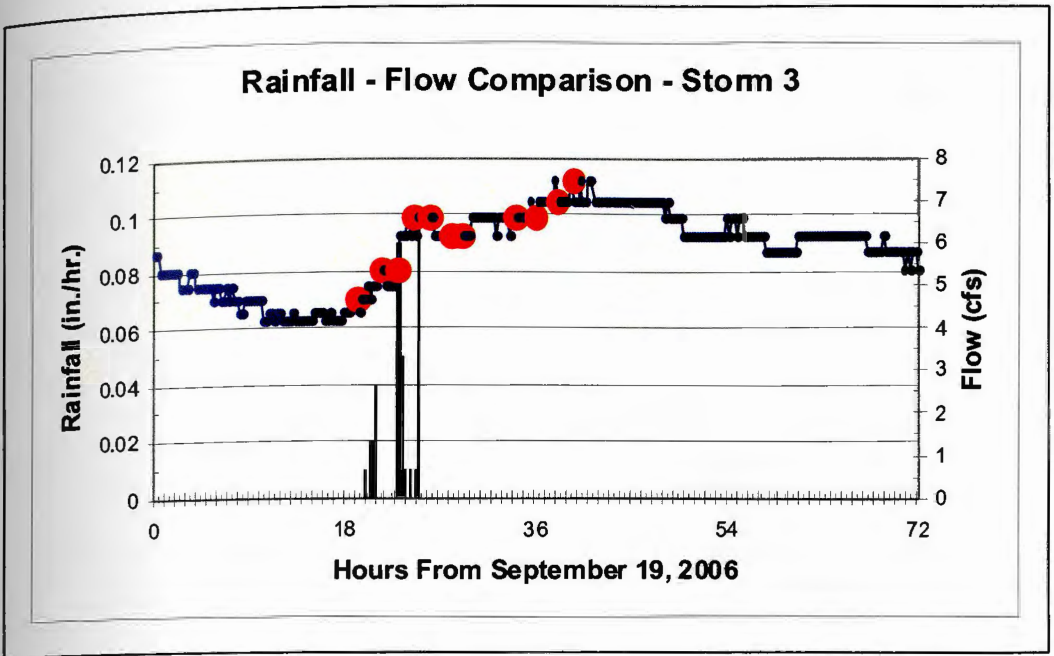
Organic & Total Coliform Bacteria Samples

Bottle I.D.	Date	Time	Flow (cfs)	Acidity (mg/L)	Alkalinity (mg/L)	Turbidity (NTU)	Color (Color Units)	Chloride (mg/L)	p H	TSS (mg/L)	T. Coliform (cfu/100mL)
1-A	7/12/2006	1:15 PM	14	14.0	ND	1.40	60	18	6.10	6.0	TNTC
2-A	7/12/2006	7:00 PM	15	14.0	ND	1.30	50	19	5.60	2.0	TNTC
3-A	7/12/2006	10:30 PM	16	10.0	ND	1.60	50	18	5.60	4.0	TNTC
4-A	7/13/2006	2:30 AM	16	16.0	ND	1.50	60	18	5.90	1.0	TNTC
5-A	7/13/2006	6:30 AM	16	16.0	ND	1.40	50	18	5.80	4.0	TNTC
6-A	7/13/2006	10:30 AM	17	1.0	ND	0.86	10	18	5.80	5.0	75
7-A	7/13/2006	2:30 PM	19	6.0	ND	1.80	60	19	5.00	7.0	380
8-A	7/13/2006	8:15 PM	20	10.0	ND	0.96	70	18	4.80	11.0	240
9-A	7/14/2006	8:30 AM	19	11.00	ND	1.60	60	19	4.70	6.0	90

6.6 Storm 3 Characteristics

The third wet weather event began on September 19, 2006 which had a total rainfall of 0.45 in., a maximum intensity of 0.24 in./hr., and a total duration of 5 hrs.. The fifteen constituents that were measured during wet weather event two were duplicated for wet weather event three. Prior to collection of storm three samples a request was made to the laboratory to correct the dilution methodology for testing total coliform bacteria in order to achieve a full set of concentrations in storm event three. During the collection period for this storm event, field techniques of sampling became much simpler due to acquiring experience from the previous dry and wet weather samples. The initial site setup, bottle preparation, sample log, preservation, and sample frequency made it much simpler to collect wet weather samples during storm three.

Results showed similar characteristics patterns of the first two storm events, which indicated zinc, copper, and alkalinity as non-detectable parameters. Concentrations of barium, manganese, aluminum, and iron decreased as expected in relation to the total rainfall and runoff amount being the least of the three storms due to the low amount of total precipitation, interception, and depression storage. In addition, characteristics such as turbidity, color, acidity, and total suspended solids also decreased in comparison to the first two storm events. The concentrations of pH and sodium levels increased unexpectedly in storm three which are closer to representative levels under normal dry weather conditions. Lastly, concentrations of copper stayed fairly close to storm event two. During storm three, the rivers response in relation to the samples collected is illustrated in Figure 6.3:



* The red circles indicate the time the sample was collected.

Figure 6.3: Rainfall – Flow Comparison – Storm 3: September 19, 2006

Table 6.4: Wet Weather 3 Results

Wet Weather Event 3 - Precipitation Total = 0.45 in., Duration = 5 hrs.
Date: September 19&20, 2006

Metal Samples

Bottle I.D.	Date	Time	Flow (cfs)	Barium (mg/L)	Zinc (mg/L)	Manganese (mg/L)	Copper (mg/L)	Aluminum (mg/L)	Sodium (mg/L)	Iron (mg/L)
1-A	9/19/2006	7:15 PM	4.70	0.013	ND	0.020	ND	0.050	14	0.38
2-A	9/19/2006	9:30 PM	5.40	0.013	ND	0.022	ND	0.054	14	0.40
3-A	9/19/2006	11:00 PM	5.40	0.013	ND	0.025	ND	0.052	14	0.52
4-A	9/20/2006	12:30 AM	6.60	0.013	ND	0.027	ND	0.058	14	0.42
5-A	9/20/2006	2:00 AM	6.60	0.012	ND	0.027	0.0010	0.064	14	0.42
6-A	9/20/2006	3:30 AM	6.20	0.012	ND	0.026	ND	0.071	14	0.39
7-A	9/20/2006	5:00 AM	6.20	0.012	ND	0.024	ND	0.055	14	0.40
8-A	9/20/2006	10:00 AM	6.60	0.012	ND	0.020	ND	0.051	14	0.36
9-A	9/20/2006	12:00 PM	6.60	0.015	ND	0.023	ND	0.052	15	0.39
10-A	9/20/2006	2:00 PM	7.00	0.016	ND	0.023	ND	0.052	15	0.40

Organic & Total Coliform Bacteria Samples

Bottle I.D.	Date	Time	Flow (cfs)	Acidity (mg/L)	Alkalinity (mg/L)	Turbidity (NTU)	Color (Color Units)	Chloride (mg/L)	p H	TSS (mg/L)	T. Coliform (cfu/100mL)
1-B	9/19/2006	7:15 PM	4.70	ND	2.7	0.60	30	26	6.80	5.7	180
2-B	9/19/2006	9:30 PM	5.40	ND	5.4	0.69	30	26	6.70	9.0	220
3-B	9/19/2006	11:00 PM	5.40	ND	ND	0.82	40	25	6.60	3.0	100
4-B	9/20/2006	12:30 AM	6.60	ND	ND	0.85	35	25	6..6	12.0	250
5-B	9/20/2006	2:00 AM	6.60	ND	5.4	0.95	35	25	6.60	7.0	530
6-B	9/20/2006	3:30 AM	6.20	ND	5.4	1.10	40	26	6.60	120.0	620
7-B	9/20/2006	5:00 AM	6.20	ND	5.4	0.87	40	26	6.60	19.0	530
8-B	9/20/2006	10:00 AM	6.60	ND	5.4	0.63	35	26	6.60	ND	130
9-B	9/20/2006	12:00 PM	6.60	0.20	ND	0.76	40	26	6.60	1.0	140
10-B	9/20/2006	2:00 PM	7.00	ND	ND	0.68	35	25	6.60	ND	300

CHAPTER 7

7 SITE SPECIFIC LOADING CHARACTERISTICS

7.1 Constituents Selected For Load Analysis

In many cases, concentrations are used to determine the health of the river over the course of several years. The constituent load can be useful to indicate the chemical mass transported past a given point in the river during a segment of time. It is important to recognize that water quality constituents vary in both time and space. Many constituents show diurnal and seasonal variations. As materials flows downstream, a portion of the load may settle and/or undergo biological or chemical transformation; thus, a significant spatial trend may be evident along the stream. (McCuen, 1998)

The loads determined for the Ponaganset River were selected based upon results acquired during dry and wet weather sampling at the site. From the 15 samples that showed detected concentrations, 6 constituents were chosen for the wet and dry weather load analysis. The selections of these 6 constituents were based upon previous historic water quality data, laboratory results, and consistency of record patterns. The following trace metals and chloride were selected for load determination based upon the consistency throughout this analysis at the Ponaganset River site: barium, manganese, aluminum, iron, sodium, and chloride.

The data collected for these six constituents was used to determine the total wet load (lbs.) for each of the three storms and twelve dry weather loads (lbs./day) for this site. Real-time monitoring of discharge and precipitation data was used to correlate to the specific time the sample was collected. The total wet load for each of the six parameters will be predicted with the use of Multiple Linear Regression (MLR) models designed for this site. The dependent variables used for these equations include the total precipitation of the storm and the rivers maximum flow rate (cfs) minus the baseflow using the concave method for predicting the total wet load. The loads used for the wet weather analysis will be converted from "lbs./day" to "lbs." by dividing the number of hours between sampling by 24. This number will be multiplied by the difference of the second through last load minus the first load in "lbs./day". After multiplying these numbers for each increment measured during the storm these values will be summed to obtain the total wet load (lbs.) for each of the three storms collected for this analysis. The twelve dry weather samples will be used to generate Linear Regression (LR) models using the baseflow discharge at the time of sampling. These equations will be described in more detail in the following chapter where the analysis is more in depth with regard to the statistical analysis for this site.

7.2 Environmental Influences of Water Quality

When rain storms occur in the watershed, biological agents, rock weathering, and soil nutrients dissolve into the river water. Contributions from the pure water also carry very small amounts of acidic chemical substances such as carbonic acid (H_2CO_3). This type of reaction takes place when carbon dioxide (CO_2), from the earth's atmosphere reacts with the water (H_2O), to form carbonic acid (H_2CO_3). The water in the river also contains small diluted amounts of hydrochloric and sulfuric acids (Dunne and Leopold, 1978). These types of acids gradually breakdown geologic formations that are characteristic to the area surrounding the site. The bedrock typically found in Rhode Island in the northern part of the state consists primarily of granite. In the southwestern portion of Rhode Island, near eastern Connecticut, bedrock consists of gneisses, metamorphosed sedimentary rock, and volcanic rock (U.S Department of Agriculture Soil Conservation Service in Cooperation with R.I. Agricultural Station, 1981). The natural breakdown of rock partly influences the water quality in the river in the form of detected trace amounts of metals such as barium, manganese, aluminum, iron, sodium, and chloride.

Soil types were also reviewed for the Ponaganset River site for the various soils within proximity of 1000 ft radius surrounding the point the samples were collected. These soil types for this area are listed in Table 7.1 and illustrated in Figure 7.1.

Table 7.1: Soil Compositions

1000 ft radius surrounding Ponaganset River Site (01115187)

Unit	Description
CeC	Canton & Charlton fine sandy loams, very rocky, 3 to 15 % slopes
ChB	Canton & Charlton very stony fine sandy loams, 3 to 8 % slopes
ChC	Canton & Charlton very stony fine sandy loams, 8 to 15 % slopes
HkD	Hinckly gravelly sandy loam, hilly
MmA	Merrimac sandy loam, 0 to 3 % slopes
MmB	Merrimac sandy loam, 3 to 8 % slopes
Nt	Ninigret fine sandy loam
Rf	Ridgebury, Whitman, & Leicester extremely stony fine sandy loams
Sb	Scarboro mucky sandy loam
Ss	Sudbury sandy loam
StB	Sutton fine sandy loam, 3 to 8 % slopes
SuB	Sutton very stony fine sandy loam, 0 to 8 % slopes
Wa	Walpole sandy loam
WoB	Woodbridge very stony fine sandy loam, 0 to 8 % slopes

Unit	Erosion Rating	Class
CeC	Potentially High Erosion Rating	6s
ChB	Potentially High Erosion Rating	6s
ChC	High Erosion Rating	6s
HkD	High Erosion Rating	6s
MmA		2s
MmB	Potentially High Erosion Rating	
Nt		2w
Rf		7s
Sb		5w
Ss		2w
StB	Potentially High Erosion Rating	2e
SuB	Potentially High Erosion Rating	6s
Wa		4w
WoB	Potentially High Erosion Rating	6s

(U.S. Department of Agriculture Soil Conservation Service in Cooperation with R.I. Agricultural Station (1981) Soil Survey of Rhode Island)

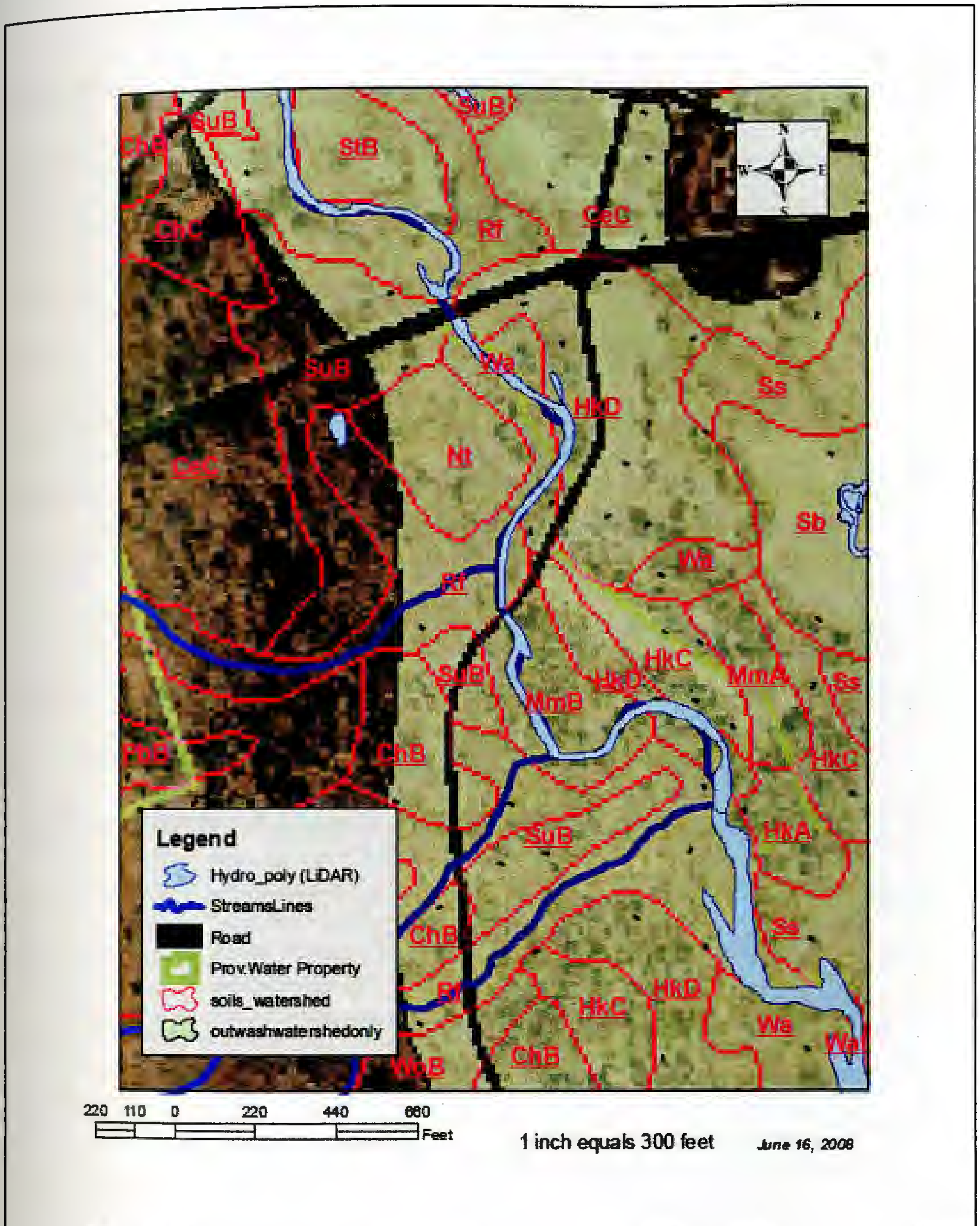


Figure 7.1: Soil Map of the Ponaganset River Site (Source: U.S. Department of Agriculture Soil Conservation Service in Cooperation with R.I. Agricultural Station (1981) Soil Survey of Rhode Island)

The purpose of including these soil types is to describe the characteristic properties of this region of the watershed. The erosion rating identifies the soils with the most significant influence upon the decomposition of vegetation in the area. In Table 7.1 the soils indicating the highest erosion rating are Canton & Charlton very stony fine sandy loam (ChC), and Hinckly gravelly sandy loam (HkD). These soils will contribute to the river's water quality by depositing as silts or outwash during wet weather conditions at the site. Soils bond to particulates that may include trace metals such as barium and manganese. These two constituents were identified historically and throughout the analysis.

The characteristics described in this section regarding water composition, geologic conditions, and soils that are particular to this site influence changes in the concentration levels of constituents measured during this analysis. The concentration of the sample, (mg/L) in direct relation to discharge, (cfs) affects the size of the load, (lbs./day) measured at the site. For this reason, real-time monitoring equipment provides more accurate estimates of the load contributions at the site. The subsequent sections in this chapter will describe the procedures used for determining loads used this analysis.

7.3 Loading Procedure

The differences between concentration and load are very different. The concentration is measured by mass per volume while loads are measured in weight per unit of time. The load formula used for this analysis is shown as follows:

$$W = K_u * C * Q$$

Where,

W	=	Load	(lbs./day)
K_u	=	Conversion Factor	(5.39) where, $K_u = (L)(lb)(sec) / (mg)(ft^3)$
C	=	Concentration	(mg/L)
Q	=	Discharge	(cfs)

The estimated daily constituent load (lbs./day) was calculated by multiplying by a conversion factor of 5.39 by the instantaneous concentration (mg/L) and an instantaneous stream flow (cfs).

$$W(x;t) = K_u C(x;t)\, Q(x;t)$$

This equation indicates that the load, concentration, and discharge show temporal and spatial variations (McCuen, 1998). The equation described above was utilized to determine the loads for six of the detected constituents described in section 7.1 in which the concentrations are all measured in mg/L. These loads were determined for 12 concentrations collected during baseflow or dry weather conditions and 29 measured concentrations during the three wet weather events for a total of 41 incremental measurements of load contributions to Ponaganset River which are measured in lbs. /day.

Wet loads were determined by separating the baseflow load from the river's runoff (cfs) at the initial, peak, and end of the storm event. The computed loads are an estimate of the contributions measured at a precise time when the sample was collected. These weight values (lbs.) were used in order to determine the total mass or wet load of the entire storm event.

7.4 Dry Weather Loads

A total of twelve dry weather samples were collected at the Ponaganset River site 01115187. The initial eight samples were collected between April 2005 threw July 2005 at intervals approximately two weeks apart. During the summer of that year, rainfall was very low and discharge reflected drought like conditions. In July 2005 the discharge at the river was 0.98 cfs. It was decided to discontinue sampling for the remainder of the year and recommence in April 2006. The remaining 4 samples were collected prior to wet weather collection for which three were utilized for this analysis.

The dry weather loads were calculated using $W = K_u * C * Q$ for each of the six trace metals selected for analysis. Five of these metals were identified twelve out of twelve times for barium, manganese, sodium, iron, & chloride. Aluminum was detected eight out of twelve times above the detection limit 0.05 mg/L although the last dry weather sample indicated 0.04 mg/L by Premier Laboratory. In Table 7.2 barium showed the smallest load concentration while chloride showed the highest. Characteristic relationships were plotted in Figure 8.1 by plotting the load in (lbs. / day) versus the discharge (cfs). The figures indicate a linear relationship for barium, manganese, aluminum, sodium, and chloride at confidence levels greater than 90 %. Iron did not show as strong of a relationship as the other five constituents having a confidence level of only 72.39%.

Table 7.2: Dry Weather Loads

Sample #	Date	Time	Flow (cfs)	Barium (lbs./day)	Manganese (lbs./day)	Aluminum (lbs./day)	Iron (lbs./day)	Sodium (lbs./day)	Chloride (lbs./day)
1	4/15/2005	12:30 PM	25.50	2.75	4.81	16.49	20.62	1649.34	3023.79
2	5/5/2005	5:15 PM	34.00	3.48	5.86		45.82	2199.12	3665.20
3	5/19/2005	12:30 PM	16.00	1.55	3.97	9.49	31.05	1121.12	1897.28
4	6/2/2005	12:30 PM	20.75	1.79	3.24		27.96	1028.95	2236.85
5	6/15/2005	12:45 PM	4.43	0.50	1.58		19.10	334.29	549.19
6	6/23/2005	12:45 PM	3.72	0.38	1.06	2.21	11.23	260.66	461.17
7	7/13/2005	12:45 PM	3.51	0.38	1.17	2.08	10.22	245.95	491.89
8	7/27/2005	12:45 PM	0.98	0.09	0.37		3.75	68.67	126.77
9	5/2/2006	9:15 AM	12.00	1.16	1.49	4.27	8.41	905.52	15552.32
10	7/12/2006	1:15 PM	14.00	1.21	1.89	8.30	27.92	830.06	1358.28
11	9/19/2006	7:15 PM	4.70	0.33	0.51	1.27	9.63	354.66	658.66
12	9/28/2006	7:30 PM	3.30	0.28	0.48	0.78	5.34	302.38	480.25

7.5 Wet Weather Loads

A total of three storm events, collected during a five month period between May and September 2006, were used for this analysis. The wet weather loads were computed from the instantaneous load W (lbs./day) for each measured increment of concentration in relation to the discharge in the river during the storm. A description of the individual tabulated loads during each of the three storms is described in Tables 7.3, 7.4, and 7.5. These figures indicate the measured increments of load in pounds that include predicted loads concentrations for the tail end of the pollutagraph to be able to determine the entire load for each constituent. In order to predict these load estimates interpretation was made of the load by means of assuming that the concentration from the initial apart of the hydrograph can be used to interpret the end of the pollutagraphs. Further descriptions of pollutagraphs are described in Appendix C for each of the storm events captured. Wet weather event 3 pollutagraphs indicated maximum loads which occurred much quicker, particularly for manganese, aluminum, and iron due to the intensity being the greatest (0.24 in/hr.) of the wet weather events. Typically, the largest loads are associated with the largest discharges measured during field collection.

Other studies, such as phase 2 of the Blackstone River Initiative have conducted more extensive analyses to identify sources of pollutants using data collected for three wet weather events. A point indicated in this previous study identified that the combination of the increase and decrease of individual constituents cause a more significant environmental impact. "The EPA has established acute and chronic concentrations for trace metals using relationships based on hardness. When hardness decreases, the potential toxicity increases." (Wright, Chaudhury, and Makam, 1994) Wet weather event 1 showed the highest load contributions based upon the amount of total precipitation (1.38 in.) and discharge in the river. The largest discharge measured at the Ponaganset River during wet weather sample collection was 82 cfs that produced the largest measured load (2,327.27 lbs) of chloride. The loads for each of the six constituents are listed from smallest to largest load contributions for storms one, two, and three:

- Barium — Smallest Load
- Manganese
- Aluminum
- Iron
- Sodium
- Chloride — Largest Load

From this portion of the analysis calculations indicate sodium and chloride to be the largest loads measured at the Ponaganset River. Even though the concentration during wet weather for sodium and chloride decreased by means of dilution large river flows during wet weather identify large load estimates. Concentrations of sodium and chloride will tend to be larger during the winters that have significant snowfall due to road salting along Rt. 6 / Danielson Pike, although large flows during the spring and fall will produce larger loads from the river.

Table 7.3: WW 1 Loads (lbs.) – May 2-4, 2008 - P_T = 1.38 in., Duration = 13 Hrs.

Sample #	Date	Time	Cum. Hrs.	Discharge (cfs)	Barium (lbs.)	Manganese (lbs.)	Aluminum (lbs.)	Iron (lbs.)	Sodium (lbs.)	Chloride (lbs.)
1	5/2/2006	9:15 AM	0.00	12						
2	5/2/2006	2:45 PM	5.50	13	0.00	0.01	0.00	0.00	8.65	6.79
3	5/2/2006	7:30 PM	10.25	15	0.02	0.01	0.11	0.21	21.87	28.79
4	5/3/2006	12:00 AM	14.75	17	0.04	0.03	0.29	044	49.02	56.09
5	5/3/2006	4:00 AM	18.75	23	0.10	0.11	0.58	1.06	90.28	128.91
6	5/3/2006	8:30 AM	23.25	38	0.29	0.43	1.82	3.81	192.52	329.46
7	5/3/2006	12:15 PM	27.00	62	0.49	1.00	3.40	7.47	321.72	557.53
8	5/3/2006	4:00 PM	30.75	79	0.77	1.68	5.94	9.75	478.36	885.56
9	5/4/2006	12:15 AM	39.00	82	1.99	3.91	17.19	20.21	1,256.21	2,300.27
10	5/4/2006	8:00 AM	46.75	66	1.74	2.80	15.36	16.03	1,124.38	2,003.34
Predicted	5/4/2006	11:00 AM	49.75	62	0.57	1.00	4.45	6.66	361.13	647.47
Predicted	5/5/2006	6:30 AM	69.25	38	2.56	5.20	17.68	38.84	1,672.92	2,899.15
Predicted	5/5/2006	2:00 PM	76.75	34	0.62	0.96	3.95	8.32	412.67	6,67.01
			Total		**9.20**	**17.14**	**70.78**	**112.8**	**5,990**	**10,510**

Table 7.4: WW 2 Loads (lbs.) – July 12-14, 2006 - P_T = 0.57 in., Duration = 3.75 Hrs.

Sample #	Date	Time	Cum. Hrs.	Discharge (cfs)	Barium (lbs.)	Manganese (lbs.)	Aluminum (lbs.)	Iron (lbs.)	Sodium (lbs.)	Chloride (lbs.)
1	7/12/2006	1:15 PM	0.00	14						
2	7/12/2006	7:00 PM	5.75	15	0.00	0.02	0.04	0.43	7.10	21.31
3	7/12/2006	10:30 PM	9.25	16	0.01	0.02	0.05	0.81	6.68	27.12
4	7/13/2006	2:30 AM	13.25	16	0.01	0.04	0.05	1.31	5.39	32.34
5	7/13/2006	6:30 AM	17.35	16	0.01	0.06	0.05	1.60	5.39	32.34
6	7/13/2006	10:30 AM	21.25	17	0.02	0.08	0.14	1.86	9.88	40.43
7	7/13/2006	2:30 PM	25.25	19	0.05	0.45	0.44	2.30	23.36	73.21
8	7/13/2006	8:15 PM	31.00	20	0.11	0.73	1.36	4.91	52.95	140.11
9	7/14/2006	8:30 AM	43.25	19	0.24	0.59	3.42	12.56	112.80	298.50
Projected	7/15/2006	2:00 PM	60.75	16	0.19	0.52	2.30	58.95	11.89	284.94
Projected	7/15/2006	12:45 PM	71.50	15	0.02	0.11	0.01	6.04	2.67	83.29
			Total		**0.66**	**2.63**	**7.87**	**40.3**	**230**	**1,034**

Table 7.5: WW 3 Loads (lbs.) – September 19-20, 2006 - $P_T = 0.45$ in., Duration = 5 Hrs.

Sample #	Date	Time	Cum. Hrs.	Discharge (cfs)	Barium (lbs.)	Manganese (lbs.)	Aluminum (lbs.)	Iron (lbs.)	Sodium (lbs.)	Chloride (lbs.)
1	9/19/2006	7:15 PM	0.00	4.70						
2	9/19/2006	9:30 PM	2.25	5.40	0.002	0.006	0.014	0.09	2.44	4.57
3	9/19/2006	11:00 PM	3.75	5.40	0.003	0.001	0.017	0.23	3.28	5.20
4	9/20/2006	12:30 AM	5.25	6.60	0.006	0021	0.033	0.34	6.11	9.34
5	9/20/2006	2:00 AM	6.75	6.60	0.007	0.028	0.056	0.33	8.94	14.40
6	9/20/2006	3:30 AM	8.25	6.20	0.005	0.025	0.066	0.27	8.00	13.76
7	9/20/2006	5:00 AM	9.75	6.20	0.005	0.021	0.052	0.22	7.05	13.11
8	9/20/2006	10:00 AM	14.75	6.60	0.018	0.052	0.116	0.72	26.66	49.56
9	9/20/2006	12:00 PM	16.75	6.60	0.013	0.021	0.047	0.31	13.40	22.16
10	9/20/2006	2:00 PM	18.75	7.00	0.020	0.028	0.053	0.40	16.23	22.92
Projected	9/21/2006	1:45 AM	30.50	6.6	0.12	0.16	0.31	2.38	95.53	134.84
Projected	9/22/2006	2:45 AM	55.50	5.4	0.13	0.23	0.46	3.26	120.72	189.77
Projected	9/22/2006	8:30 AM	61.25	4.7	0.01	0.02	0.04	0.24	6.33	11.75
			Total		**0.33**	**0.62**	**1.26**	**8.8**	**315**	**492**

A summary of the total loads for each of the six parameters was extracted from Tables 7.3, 7.4, and 7.5 to create Table 7.6 which shows only the total load for each of the three collected wet weather events: barium, manganese, aluminum, sodium, iron, and chloride.

Table 7.6: Summary of WW Loads at the Ponaganset River

Storm #	Date	Barium (lbs.)	Manganese (lbs.)	Aluminum (lbs.)	Iron (lbs.)	Sodium (lbs.)	Chloride (lbs.)
1	5/2-4/06	9.20	17.14	70.78	112.8	5,990	10,510
2	7/12-14/06	0.66	2.63	7.87	40.3	230	1034
3	9/19-20/06	0.33	0.62	1.26	8.8	315	492

The results show a consistent pattern of load based upon the total precipitation. As the total precipitation increases in direct correlation with the rivers discharge, the total pollutant load increases and vice versa. If the storm event is large enough to produce a wet weather event in excess of one inch or greater of total precipitation, the pollutant load will increase significantly. The other five constituent results show a more significant difference between storms 1 and 2 with regard to the individual storm characteristics. Each of the three storms collected for this analysis, resulted in the loads generally corresponding to the amount of total rainfall (1.38, 0.57, and 0.45 in.), and the discharge response of the river at the time the sample was collected.

In the next chapter, the total loads for each of the three storm events will be used to predict the estimated load contributions through the use of developed linear and multiple linear regression models specific to the Ponaganset River site. These statistical models will identify significant advantages over periodic manual sampling practices. The predicted chemical load transported at the Ponaganset River site will be used to determine the amount of pounds per year during both wet and dry weather conditions. During periods of high flows, the river has a substantial effect on the transport of these chemicals. Therefore, estimated loads are far more accurate using real-time water quality monitoring sites such as the Ponaganset River. The data described in Tables 7.3, 7.4, and 7.5 identifies the load (lbs.) during the time of sampling throughout each of the three captured storm events. The summation of total load per storm event is summarized in Table 7.6 for each of the six constituents. These observed loads will be used in comparison to predicted loads for which statistical analysis will identify if there is a correlation. This data can later be used to provide estimated event and annual based load estimates for the Ponaganset River site.

CHAPTER 8

LINEAR AND MULTIPLE LINEAR REGRESSION ANALYSIS

8.1 Regression Analysis Overview

The concept behind Multiple Linear Regression (MLR) analysis relates to one dependent variable that is conditioned by more than one independent variable. In this analysis, regression equations were generated based upon the physical properties and analysis criteria of river water samples collected in 2005 and 2006 at the Ponaganset River site. These MLR equations will be used to determine loads during wet weather for various size storm events that occur between the months of April through September 2003. In addition, Total Maximum Daily Loads (TMDL) can be determined with the use of the MLR models generated from data collected at the Ponaganset River site. Many states now mandate that TMDL's be recorded for stream segments identified by the 1972 Clean Water Act as limited for specific uses due to water quality concerns.

As a result of water quality data retrieved at the Ponaganset River site, six metals were selected for use in this analysis to determine load estimates during dry and wet weather conditions. The form of the predicted LR and MLR equations utilized for this study is identified in the general form described below:

$y_1 = B_1x_1 + B_0$ Linear Regression Model

$y_2 = B_1x_1 + B_2x_2 + B_0$ Multiple Linear Regression Model

Where,

y_1	is the dry weather load (lbs.)
y_2	is the wet weather load (lbs.)
B_0	is the intercept
B_1	is the slope coefficient for the first explanatory variable
B_2	is the slope coefficient for the second explanatory variable
x_1	is the first independent variable where, $x_1 = Q_{AVE.}$ for LR and $x_1 = P_T$ for MLR
x_2	is the second independent variable, where, $x_2 = Q_{Max.\text{-}B.F.}$

The LR and MLR models were used for the six wet weather equations and six dry weather equations for the dependent variable or load for the constituents listed as follows: barium, manganese, aluminum, sodium, iron, and chloride. The independent variables were selected based upon how they relate to the dependent variable or load during both dry and wet weather conditions at the Ponaganset River site.

<u>DW Independent Variable</u>

x_1 = Average Hourly Discharge = $Q_{AVE.}$

WW Independent Variables

x_1 = Maximum Discharge – Base Flow = $Q_{MAX.-B.F.}$

x_2 = Total Precipitation = P_T

The $Q_{MAX.\ -\ BASE\ FLOW}$ and P_T are used in this equation as explanatory variables to measure the storm characteristics as they relate to the wet weather conditions at the Ponaganset River site. The data used to predict these MLR equations was collected from the Ponaganset River site's real-time water quality monitoring equipment along with the analysis results. The information published for this station is relayed to the internet approximately four hours after the actual time it is collected at the site. The real time data initially collected was provisional, although later the data was adjusted after publication of the 2004 USGS fiscal data. The data collected at real-time stations often requires adjustments due to minor glitches, adjustment, and freezing. The Ponaganset River site's real time monitoring capabilities provides more of an accurate determination of discharge and precipitation at a precise time than conventional water quality sites. Using data collected from the river, in conjunction with water quality results collected at a precise time, allowed this analysis to determine predicted estimates of load contributions for selected constituents.

The loads described in chapter 7 were used in conjunction with real time data to generate predictive linear and multiple linear regression equations. These predicted constituent loads can be used to determine the event and annual based pollutant loads during dry and wet weather conditions. Information generated from this analysis can be used to indicate the sub-basin load contributions as it relates to land-resource management practices within the Scituate Reservoir

Complex. Finally, the use of these predictive equations can be used to estimate peak loads during extreme conditions. If changes do occur these equations could provide the water supplier with sufficient time to respond to any negative effects on the environment or allow them to make adjustments to the water treatment processes.

8.2 Linear Regression Analysis

Linear Regression models were developed to predict the estimated load contributions at the Ponaganset River site (01115187) during dry weather conditions. This was done by graphing the load (lbs./day) versus discharge (cfs) for the 12 samples collected during dry weather conditions. The Linear Regression equations were developed based upon data collected at the site for the 12 dry weather samples. These equations are valid for use as an estimate of the load during dry weather if the antecedent dry period is equivalent to two or more days during the spring and summer months at the precise location where the sample was collected.

The establishment of these Linear Regression models was then taken one step further by merging the historic PWSB water quality data with the twelve current analysis samples. To do this, data collected from PWSB was first reviewed to identify the types of metals that have been detected at the Ponaganset River site since testing began. PWSB's historic water quality results used for a comparison in this analysis were collected by PWSB personal and tested by either Premier Laboratory or Rhode Island Analytical. Metals have been tested at this site since May 2000 to the present day and are tested on a quarterly basis by water resource division at PWSB. From May 11, 2000 to March 25, 2008 a total of 31 sets of samples were collected and tested at this site. These 31 sets of samples include numerous types of metals and other parameters not mentioned in this analysis because they were not detected or that the number of times it was detected was inconclusive for this analysis. From the historic segment of water quality data used in this analysis only nine metals were detected over the course of eight years as shown in Table 8.1. The majority of the historic data showed an insufficient amount of data to compare to the analysis data although it did assist in the preliminary planning stages of this analysis.

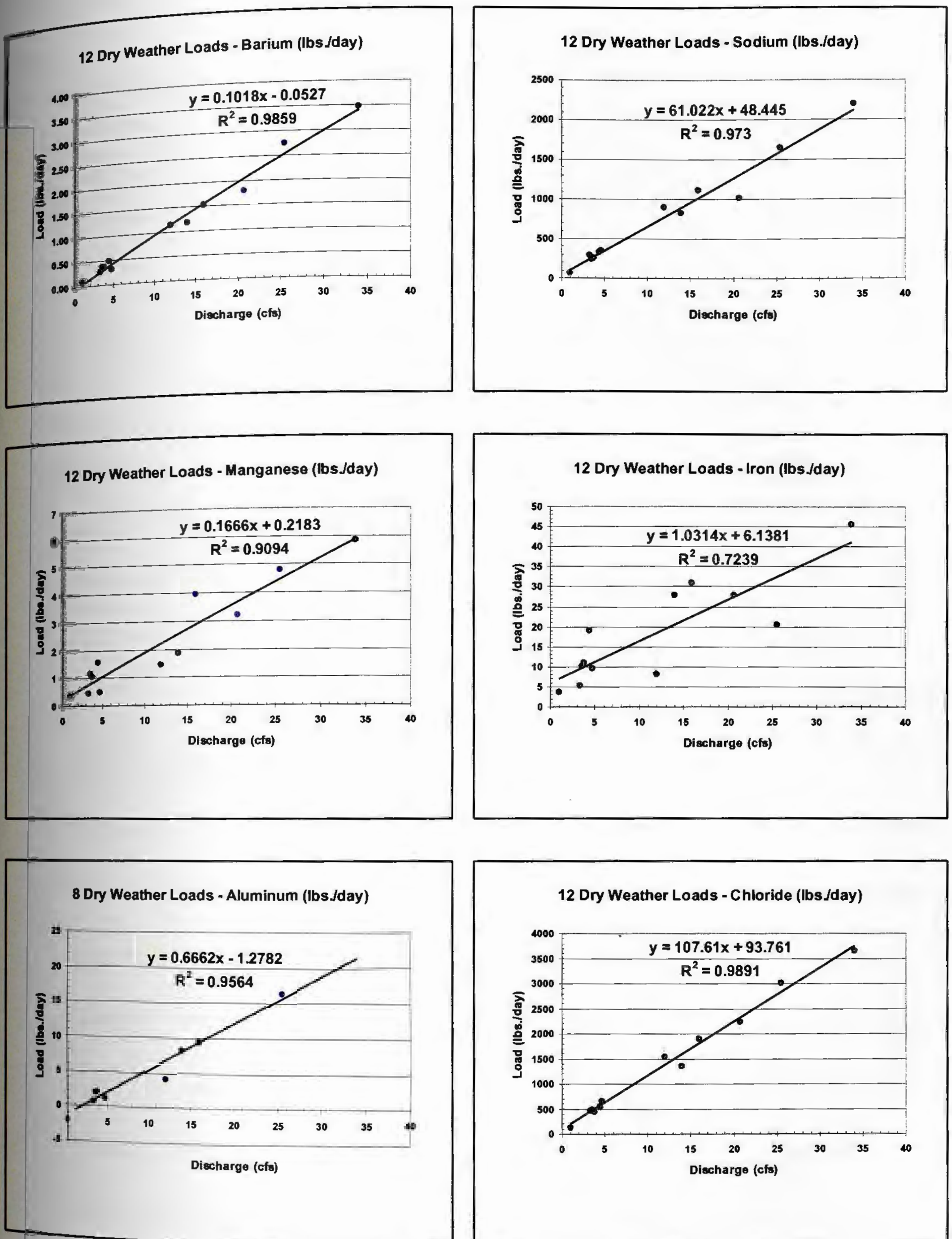


Figure: 8.1: Predicted Dry Weather Linear Regression Models

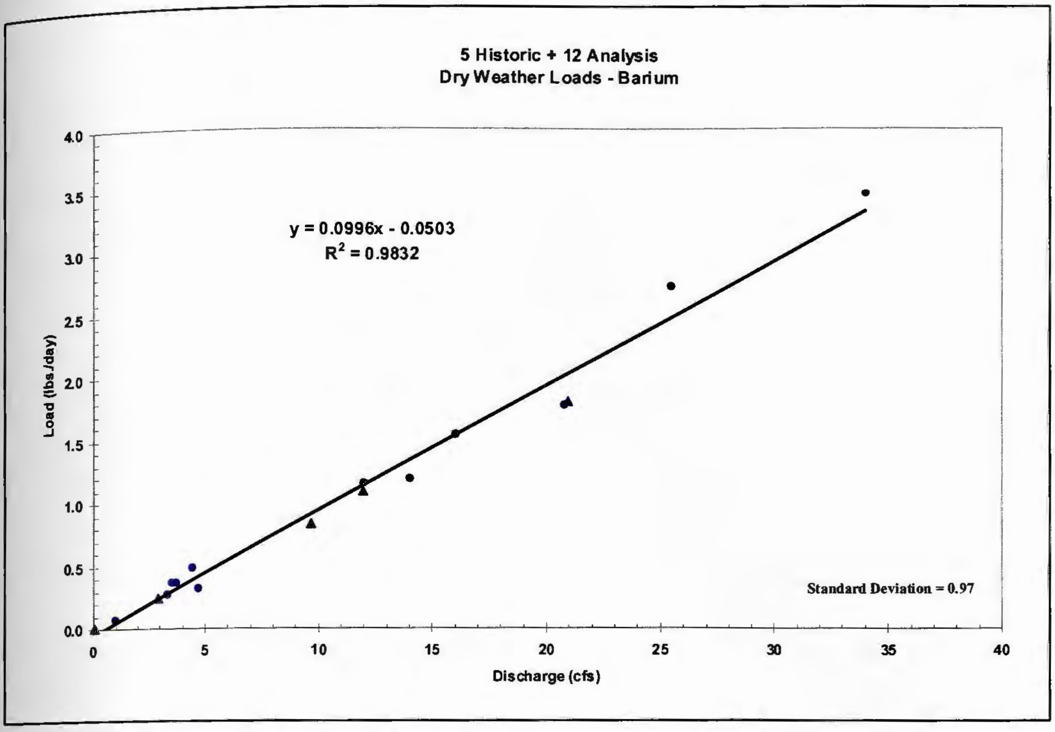
Table 8.1: Ponaganset River Frequency of Detection of Historic Trace Metals May 11, 2000 to March 25, 2008

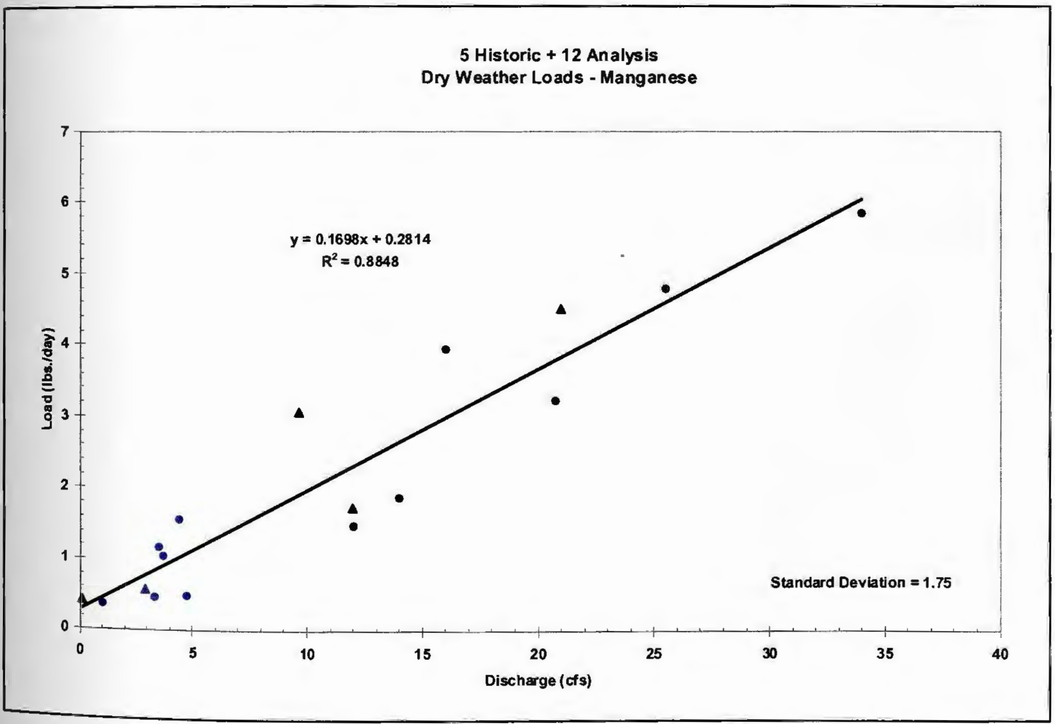
Metals	# Times Detected
Barium	31
Chromium	7
Lead	1
Zinc	10
Copper	4
Iron	1
Manganese	30
Sodium	5
Vanadium	4

* (Tested quarterly by Premier Laboratory)

During base flow conditions at the Ponaganset River site, two primary metals, barium and manganese, were detected in both historic and analysis results combined. Zinc was detected 10 out of 31 times tested, although the analysis results determined zinc 7 out of 12 dry weather samples in the river typically at higher base flow conditions and larger wet weather events observed for wet weather event one. Of the 31 historic PWSB samples only five samples were used for both barium and manganese due to past data not fulfilling the dry weather criteria of 2 days antecedent dry period as well as the months that the samples were collected (April through September). The intent of merging the 17 data points together was to determine if they fall within an acceptable range of the analysis data as well as showing how future load data can be used to produce a more precise dry weather model for these specific constituents. The resulting modified linear regression equation for barium and manganese are illustrated in

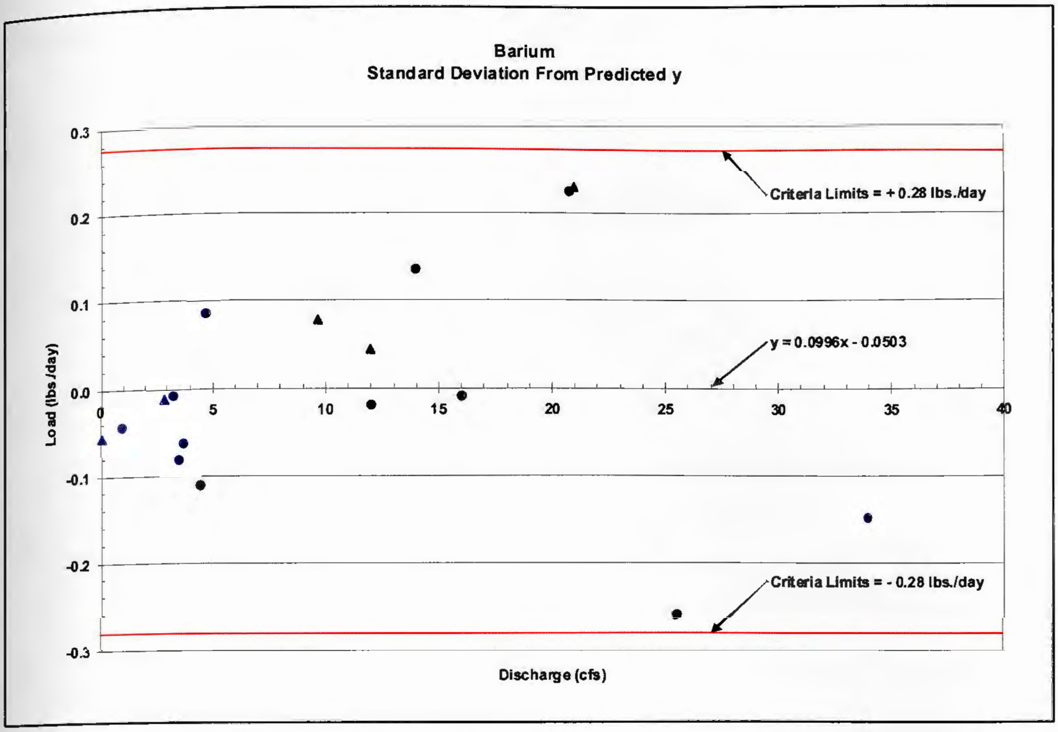
Figure 8.2 and identified in Equation 1a and 2a. In Figure 8.3 the standard deviation from equation 1a and 2a was also determined setting the acceptable range for barium at +/– 0.28 and manganese at +/- 1.0 lbs./day. Barium loads all fell within this criteria, although manganese had one outlier which fell -0.16 lbs/day outside of the criteria range indentified in Figure 8.3.

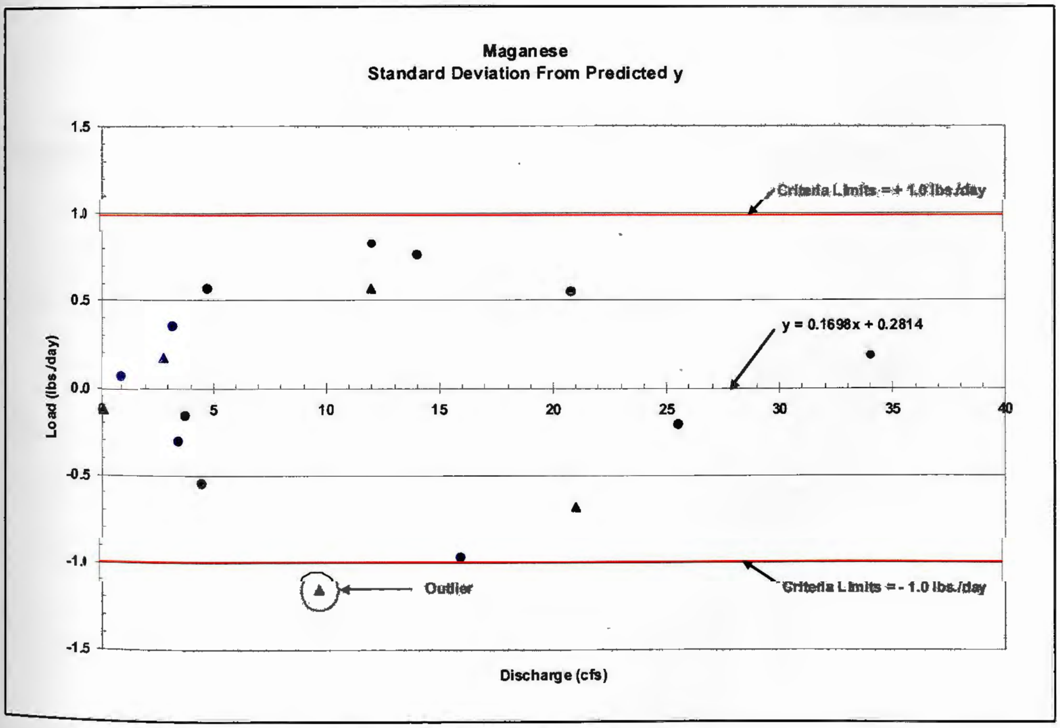




* Note: Analysis Loads = ● and Historic Loads = ▲

Figure 8.2: Linear Regression Model for Merged Historic and Analysis Data for Barium and Manganese





* Note: Analysis Loads = ● and Historic Loads = ▲

Figure 8.3: Standard Deviation of Historic and Analysis Data for Barium and Manganese

Predicted Linear Regression Models For Dry Weather Conditions

(1) Barium

$y = 0.1018 * (\text{Discharge}) - 0.0527$ $R^2 = 0.9859$ or 98.59 % Confidence Level

(2) Manganese

$y = 0.01666 * (\text{Discharge}) - 0.2183$ $R^2 = 0.9094$ or 90.94 % Confidence Level

(3) Aluminum

$y = 0.6662 * (\text{Discharge}) - 1.2782$ $R^2 = 0.9564$ or 95.64 % Confidence Level

(4) Sodium

$y = 61.022 * (\text{Discharge}) + 48.445$ $R^2 = 0.973$ or 97.30 % Confidence Level

(5) Iron

$y = 1.0314 * (\text{Discharge}) + 6.1381$ $R^2 = 0.7239$ or 72.39 % Confidence Level

(6) Chloride

$y = 107.61 * (\text{Discharge}) + 93.761$ $R^2 = 0.9891$ or 98.91 % Confidence Level

Modified Linear Regression Models For Dry Weather Conditions

(1a) Barium

$y = 0.0996 * (\text{Discharge}) - 0.0503$ $R^2 = 0.9832$ or 98.32 % Confidence Level

(2a) Manganese

$y = 0.1698 * (\text{Discharge}) + 0.2814$ $R^2 = 0.8848$ or 88.48 % Confidence Level

Discharge is measured in (cfs)

Load is measured in (lbs./day)

8.3 Multiple Linear Regression Equations

The multiple linear regression equations developed for this analysis were based upon data collected during three measured storm events during a five month period of May through September 2006. This number of storms may appear to be incomplete for an analysis such as this, although results show a very close prediction of what the actual load will be at this site. The analysis results indicate a clear representation of storms that range from 0.45 in. to 1.38 in. of total precipitation during collection of samples at the Ponaganset River site. The least squares estimation technique (Helsel and Hirsch, 1992) was used to determine the MLR equations for the wet weather conditions at the site. This was achieved by solving three normal equations with three unknowns shown below:

Normal Equations

$$\sum y = \alpha n + \beta_1 \sum x_1 + \beta_2 \sum x_2$$

$$\sum yx_1 = \alpha \sum x_1 + \beta_1 \sum x_1^2 + \beta_2 \sum x_1x_2$$

$$\sum yx_2 = \alpha \sum x_2 + \beta_1 \sum x_1x_2 + \beta_2 \sum x_2^2$$

In these three equations α, β_1, and β_2 are the three unknowns which are used as predictive factors in the MLR equation for each constituent. These normal equations require information from the Figure 8.4 to determine the three unknowns for each constituent. These unknowns can be determined by running the simultaneous equations described in Figure 8.5 for each of the six metals. The resulting three unknowns, α, β_1, and β_2 described in Table 8.2 which was used to produce the predictive model of the MLR equations shown in Equations 7 thru 12 for each of the six metals.

Barium

	y	x_1	x_2	x_1^2	x_2^2	x_1x_2	yx_1	yx_2
	9.20	1.38	78.00	1.90	6,084.00	107.64	12.70	717.60
	0.66	0.57	8.00	0.32	64.00	4.56	0.38	5.28
	0.33	0.45	5.80	0.20	33.64	2.61	0.15	1.91
Σ	**10.19**	**2.40**	**91.80**	**2.43**	**6,181.64**	**114.81**	**13.22**	**724.79**

Manganese

	y	x_1	x_2	x_1^2	x_2^2	x_1x_2	yx_1	yx_2
	17.14	1.38	78.00	1.90	6,084.00	107.64	23.65	1,336.92
	2.63	0.57	8.00	0.32	64.00	4.56	1.50	21.04
	0.62	0.45	5.80	0.20	33.64	2.61	0.28	3.60
Σ	**20.39**	**2.40**	**91.80**	**2.43**	**6,181.64**	**114.81**	**25.43**	**1,361.56**

Aluminum

	y	x_1	x_2	x_1^2	x_2^2	x_1x_2	yx_1	yx_2
	70.78	1.38	78.00	1.90	6,084.00	107.64	97.68	5,520.84
	7.87	0.57	8.00	0.32	64.00	4.56	4.49	62.96
	1.26	0.45	5.80	0.20	33.64	2.61	0.57	7.31
Σ	**79.91**	**2.40**	**91.80**	**2.43**	**6,181.64**	**114.81**	**102.73**	**5,591.11**

Iron

	y	x_1	x_2	x_1^2	x_2^2	x_1x_2	yx_1	yx_2
	112.81	1.38	78.00	1.90	6,084.00	107.64	155.68	8,799.18
	40.34	0.57	8.00	0.32	64.00	4.56	22.99	322.72
	8.80	0.45	5.80	0.20	33.64	2.61	3.96	51.04
Σ	**161.95**	**2.40**	**91.80**	**2.43**	**6,181.64**	**114.81**	**182.63**	**9,172.94**

Sodium

	y	x_1	x_2	x_1^2	x_2^2	x_1x_2	yx_1	yx_2
	5,989.72	1.38	78.00	1.90	6,084.00	107.64	8,265.81	467,198.16
	230.25	0.57	8.00	0.32	64.00	4.56	131.24	1,842.00
	314.95	0.45	5.80	0.20	33.64	2.61	141.73	1,826.71
Σ	**6,534.92**	**2.40**	**91.80**	**2.43**	**6,181.64**	**114.81**	**8,538.78**	**470,866.87**

Chloride

	y	x_1	x_2	x_1^2	x_2^2	x_1x_2	yx_1	yx_2
	10,509.85	1.38	78.00	1.90	6,084.00	107.64	14,503.59	819,768.30
	1,033.59	0.57	8.00	0.32	64.00	4.56	589.15	8,268.72
	491.66	0.45	5.80	0.20	33.64	2.61	221.25	2,851.63
Σ	**12,035.10**	**2.40**	**91.80**	**2.43**	**6,181.64**	**114.81**	**15,313.99**	**830,888.65**

Figure 8.4: Normal Equation Data for Selected Constituents

Barium

$10.19 = \alpha\,(3) + \beta_1\,(2.4) + \beta_2\,(116.5)$

$13.22 = \alpha\,(2.4) + \beta_1\,(2.43) + \beta_2\,(114.81)$

$724.79 = \alpha\,(91.80) + \beta_1\,(114.81) + \beta_2\,(6181.64)$

Manganese

$20.39 = \alpha\,(3) + \beta_1\,(2.4) + \beta_2\,(91.80)$

$25.43 = \alpha\,(2.4) + \beta_1\,(2.43) + \beta_2\,(114.81)$

$1361.56 = \alpha\,(91.80) + \beta_1\,(114.81) + \beta_2\,(6181.64)$

Aluminum

$79.91 = \alpha\,(3) + \beta_1\,(2.4) + \beta_2\,(91.80)$

$102.73 = \alpha\,(2.4) + \beta_1\,(2.43) + \beta_2\,(114.81)$

$5591.11 = \alpha\,(91.80) + \beta_1\,(114.81) + \beta_2\,(6181.64)$

Iron

$161.95 = \alpha\,(3) + \beta_1\,(2.4) + \beta_2\,(91.80)$

$182.63 = \alpha\,(2.4) + \beta_1\,(2.43) + \beta_2\,(114.81)$

$9172.94 = \alpha\,(91.80) + \beta_1\,(114.81) + \beta_2\,(6181.64)$

Sodium

$6534.92 = \alpha\,(3) + \beta_1\,(2.4) + \beta_2\,(91.80)$

$8538.78 = \alpha\,(2.4) + \beta_1\,(2.43) + \beta_2\,(114.81)$

$470866.87 = \alpha\,(91.80) + \beta_1\,(114.81) + \beta_2\,(6181.64)$

Chloride

$12035.10 = \alpha\,(3) + \beta_1\,(2.4) + \beta_2\,(91.80)$

$15313.99 = \alpha\,(2.4) + \beta_1\,(2.43) + \beta_2\,(114.81)$

$830888.65 = \alpha\,(91.80) + \beta_1\,(114.81) + \beta_2\,(6181.64)$

Figure: 8.5 Descriptions of Normal Equations For Selected Constituents

Table 8.2: Solved Unknowns for Selected Constituents

	Barium	**Manganese**	**Aluminum**	**Iron**	**Sodium**	**Chloride**
α	-0.71	-11.62	-37.64	-209.00	1763.92	-2063.13
β_1	0.86	27.60	84.15	529.19	-4812.38	4421.19
β_2	0.11	0.12	-0.10	-5.24	139.36	82.94

The MLR equations described in Equations 7 through 12 are listed in order from the smallest to the largest load contribution at the Ponaganset River site:

Predicted Wet Weather Multiple Linear Regression Equations

(7) Barium

y = 0.86 * (Total Precipitation) + 0.11 * (Peak Discharge – Base Flow) – 0.71

(8) Manganese

y = 27.60 * (Total Precipitation) - 0.12 * (Peak Discharge – Base Flow) – 11.62

(9) Aluminum

y = 84.15 * (Total Precipitation) – 0.10 * (Peak Discharge – Base Flow) – 37.64

(10) Iron

y = 529.19 * (Total Precipitation) – 5.24 * (Peak Discharge – Base Flow) – 209.00

(11) Sodium

y = -4812.38 * (Total Precipitation) + 139.36 * (Peak Discharge – Base Flow) + 1763.92

(12) Chloride

y = 4421.19 * (Total Precipitation) + 82.94 * (Peak Discharge – Base Flow) – 2063.13

Where,

Total Precipitation (in.)

Peak Discharge – Base Flow (cfs)

These MLR equations use the total precipitation and peak discharge as the independent variables used to predict the load (lbs.) for a specific wet weather event. These independent variables were specifically chosen to easily obtain data collected from storms utilizing the real-time monitoring equipment at the site. The equations described in equations 7 thru 12 were used to determine the predicted loads for each of six constituents during each of the three storms which were compared to the actual load summarized in Table 8.3. In this comparison the actual versus predicted data are dependent because the actual values were used to derive the MLR models. These predicted MLR equations can be tested in the future by conducting more wet weather monitoring to identify if the predicted load y (lbs.) falls within an acceptable range of the actual load.

Table 8.3: Actual Versus Predicted Wet Weather Loads (lbs.)

	Storm 1		**Storm 2**		**Storm 3**	
	Actual	**Predicted**	**Actual**	**Predicted**	**Actual**	**Predicted**
Barium	9.20	9.06	0.66	0.66	0.33	0.32
Manganese	17.14	17.11	2.63	3.15	0.62	0.10
Aluminum	70.87	70.69	7.87	9.53	1.26	-0.35
Iron	112.81	112.56	40.34	50.72	8.80	-1.26
Sodium	5989.72	5992.92	230.25	135.74	314.95	406.64
Chloride	10509.85	10507.43	1033.59	1120.47	491.66	407.46

The actual versus predicted loads (lbs.) shown in Table 8.3 were fairly close for the first wet weather event while storms two and three indicate more significant differences. The predicted loads during storm three indicate all positive loads except for aluminum and iron which indicate negative load amounts. These negative predicted loads obviously do not decrease below zero pounds of aluminum and iron. In these cases, the equations developed for this analysis cannot predict loads for storms characteristic of the third storm collected during wet weather monitoring. The data described in Table 8.3 identify that the predicted equations appear to have some significant error associated with storm 3. This error could be due to the statistical fit of the data, or the equation has limitations to the size of the storm it can predict. From the comparison of this data it would appear that these MLR equations can be used for storms with a total precipitation of greater than 0.5" of rain and an antecedent dry period of at least two or more days. In the following chapter these predicted MLR equations shown in Equations 7 thru 12 will be used to predict monthly and partial annual load estimate for one year worth of data supplied by the USGS.

In the case of MLR models generated for sodium and iron during wet weather, it was decided to eliminate iron for predicting monthly and annual load estimates due to variations of the actual (8.80 lbs.) versus predicted load (-1.26 lbs.) shown in Table 8.3 during wet weather event three. Sodium loads predicted for wet weather were based upon the weighted ratio 60:40 of $CaCl_2$ and NaCl mixture for road salting on State maintained roads in the Scituate Reservoir watershed. This mixture was determined based upon previous research performed by Runge and Wright (1990) comparing road density and median stream-sodium concentrations for the period of 1983 through 1989 and 1990 through 2000.

In reviewing the salting mixture $CaCl_2$ and NaCl indicated by the weighted ratio 60:40 using atomic weight for the compounds, the breakdown is described as follows:

$CaCl_2 6H_20$	:	NaCl	
40.08 + 2*(35.45) + 6((2*(1.01) + 16.00)	:	22.99 + 35.45	g moles
219.1	+	58.4	g moles

Based upon 100 lbs. of salt,

60 lbs. of $CaCl_2 + 6H_20$ where, Cl_2/ $CaCl_2 + 6H_20$ = 70.9/219.1*60 = 19.4 lbs. of Cl_2

40 lbs. of NaCl where, Cl/NaCl = 35.5/58.4*40 = 24.3 lbs. of Cl_2

Total Cl_2 = 43.7

Sodium

23.0/58.4*40 = 15.8 lbs. Na

15.8/43.7 = 0.36

This is indicated by the ratio:

64:36

For $CaCl_2$ there is an association with water or $6H_2O$ that must be included to account for the moisture content. For the purposes of load estimation for the analysis 40% of Na was used based upon the chloride load for this specific constituent. In the future, a more precise empirical model could be generated for sodium with the addition of data for one or two more collected storm events for this site for storms that range between 0.45 in and 1.38 in. of total precipitation and greater than 1.38 in..

8.4 Applicability of Statistical Models

The linear and multiple linear regression models were generated for barium, manganese, aluminum, iron, sodium, and chloride. These water quality parameters were selected based upon historically detectable trace elements observed in the sub-basin. The statistical models were based upon data that was collected during months of April through September. The reason for sampling during these months was to capture the period of highest concentrations due to the vegetation, soil drainage, and temperature for the majority of constituents which typically occur in the spring and summer months. The statistical models are only applicable to this period. Loads estimated using the equations will diminish if they are used outside the parameters of the analysis. Future collection of data for the fall and winter may require the additional development of seasonal equations. Therefore, water quality monitoring, particularly during wet weather should continue on the watershed. Since PWSB performs routine monitoring during dry weather, that data may be used as a base line for steady state flow in the rivers. The purpose of these statistical models is to develop a tool to determine long term load estimates. These long term estimates will indicate mass load for constituents having the largest impact to Barden Reservoir and its ultimate contribution to the Scituate Reservoir. Many of these constituents are dissolved and pass through the filtration process which then ultimately enters the distribution system.

During the fall period, leaf litter changes the runoff. Leaves begin to fall from October through December. At this time, the surface runoff will decrease as a result of leaf coverage. In addition to the coverage of the leaves, the vegetation begins to die which, reduces the interception, and frost begins which also reduces the soil drainage. If the models are applied to the fall load, estimates will be larger than what the actual load will be. In the winter, the direct runoff increases even more. This is due to the lack of interception, depression storage, and accumulation of snow pack. In addition, in the winter the precipitation occurs in the form of snow which covers the surface area. The snow pack continues until the temperature increases in the early spring then precipitation suddenly begins to wash the snow pack into the river as well as the precipitation that falls. Also in the winter the river level is primarily affected by the ground water discharge from below the frost line much like dry weather but lacking nutrients that are present during spring and summer months. Sodium and chloride will begin to increase after the first snowfall and particularly when temperatures start to increase and wet weather occurs which will wash a significant amount of road salt into the river.

CHAPTER 9

DETERMINATION OF MONTHLY AND ANNUAL LOADS

9.1 Annual Parameter Objectives

The data utilized to compile the annual based loading contributions associated with the Ponaganset River site 01115187 located near South Foster was received in cooperation with representatives of the United States Geological Survey (USGS). The initial data consisted of provisional recorded fifteen minute interval gauge height, specific conductance, discharge, & precipitation records between October 1, 2003 to September 30, 2004. The provisional data was later adjusted by USGS and the published data was used to determine the total estimated dry and wet weather load contributions for a period of one year. To obtain the estimated dry weather loads, discharge measurements required interpretation during periods of wet weather in order to accurately evaluate the rivers characteristic patterns for that year. The annual wet weather conditions could not be predicted for the entire year due to the range of storms collected for this analysis. The multiple linear regression equations developed for predicting the wet load can only be used for storms within a range of approximately 0.45” to 1.38” of total precipitation, a two day antecedent dry period during the months of April to September at this specific site for equations 7 through 12 in chapter eight.

9.2 Annual Data Analysis

The final objective of this analysis entailed determining a partial estimated annual load estimate of selected constituents during dry and wet weather conditions utilizing the equations developed for the Ponaganset River site. The purpose of determining these annual loads and yields may be useful to assess environmental impacts over time on the water quality at this site and its contribution to the Scituate Reservoir watershed. In addition, annual constituent loads may be important for planning future development in and around the surrounding watershed that may impact the water quality. It is important to perform continuous testing throughout all the major river systems that contribute to the Scituate Reservoir to identify any sudden changes to the water quality. The compilation of current and past historic water quality data can be used to determine whether or not the measured constituents are acceptable in relation to historic records and the EPA's secondary water quality guidelines.

The annual data required extensive time to format in such a way to be able to correspond with the analysis predictions. The initial data was recorded at continuous fifteen minute intervals. This data was then filtered to hourly intervals for which discharge (cfs) was averaged and the precipitation (in.) was summed to reduce the size of the data set. This was accomplished by compressing the initial 35,040 incremental readings by averaging four incremental fifteen minute readings between each hour to obtain average hourly intervals or 8,760 incremental readings of discharge and precipitation readings for a period of one year. These measured intervals were taken from the period of October 1, 2003 at 12:00 AM to September 30, 2004 at 11:00 PM (USGS 2004 Fiscal Year). This data was used in correlation with linear and multiple linear regression equations to predict the estimated annual loads for selected constituents measured at this site.

After the initial data was sorted, filtered, and reviewed for consistency and accuracy individual storm events were extracted from the data for a years worth of record. A total of 42 initial hydrographs were constructed and evaluated to determine the area under the hydrograph by separating the base flow and calculating the percentage of effective runoff contributions. Later, the hydrographs were reevaluated and a majority of them were eliminated due to seasonal criteria, antecedent dry periods less than two days, irregular precipitation patterns associated with summer thunderstorms, or storms less than or larger than those collected for the purposes of this analysis.

The equations developed for this site during wet weather indicated that accurate predictions of loads could not be made for an entire year for wet weather conditions based upon the storms collected for this analysis. In addition, sodium loads could not be predicted under wet weather, although chloride loads were predicted. Sodium loads were estimated in terms of chloride by recognizing that sodium chloride (NaCl) concentrations infiltrate from road salting during the winter months which can be identified in a 40:60 ratio of concentration of these two constituents. "In 1990, the Rhode Island Department of Transportation (RIDOT), in cooperation with Providence Water Supply Board (PWSB), adopted the use of a 60:40 mixture of calcium chloride and sodium chloride, mixed with sand, in place of sodium chloride and sand, on State-maintained highways in the drainage basin" (Water-Resources Investigations Report 02-4149). The purpose of this implementation was intended to reduce the sodium application rate by approximately 40 percent on State-maintained highways in the Scituate Reservoir Watershed which was intended to lower the sodium concentration in the water supply (Rhode Island Department of Administration, 1988) and (Runge, 1989).

Review of the annual water quality records collected from PWSB from Nov. 1995 to Nov. 2008 (13 years of data) indicate an increase in chloride concentrations illustrated in Figure 9.1, which therefore increases the sodium in the water. The power trend line shown in Figure 9.1 for chloride indicates an accuracy of $R^2 = 55.1\%$. Results from previous analyses done by (Runge) and (Wright) identify a significant increase in sodium and chloride trends in 1986 and 1987 at 22 sub-basins throughout the entire watershed. Results indicated that both roadway and residential density were high in the eastern portion of the watershed with Moswansicut sub-basin having the highest (1.74% and 20.33%, respectively). Kent sub-basin had the lowest roadway and residential densities (0.15% and 0.82%, respectively) (Runge, 1989). USGS has previously predicted chloride concentrations using their predicted MLR equations for the Little Arkansas River in terms of specific conductance and discharge using logarithmic transformation (Christensen, Jian, and Ziegler, 1995). Earlier analysis attempted to use these predictive parameters for use in this analysis for estimating loads during wet weather at the Ponaganset River, although a strong correlation could not be made this way. Iron also could not be accurately determined during wet weather conditions due to results received for wet weather event number two. These results skewed the results of the predicted MLR equations used to predict loads during wet weather.

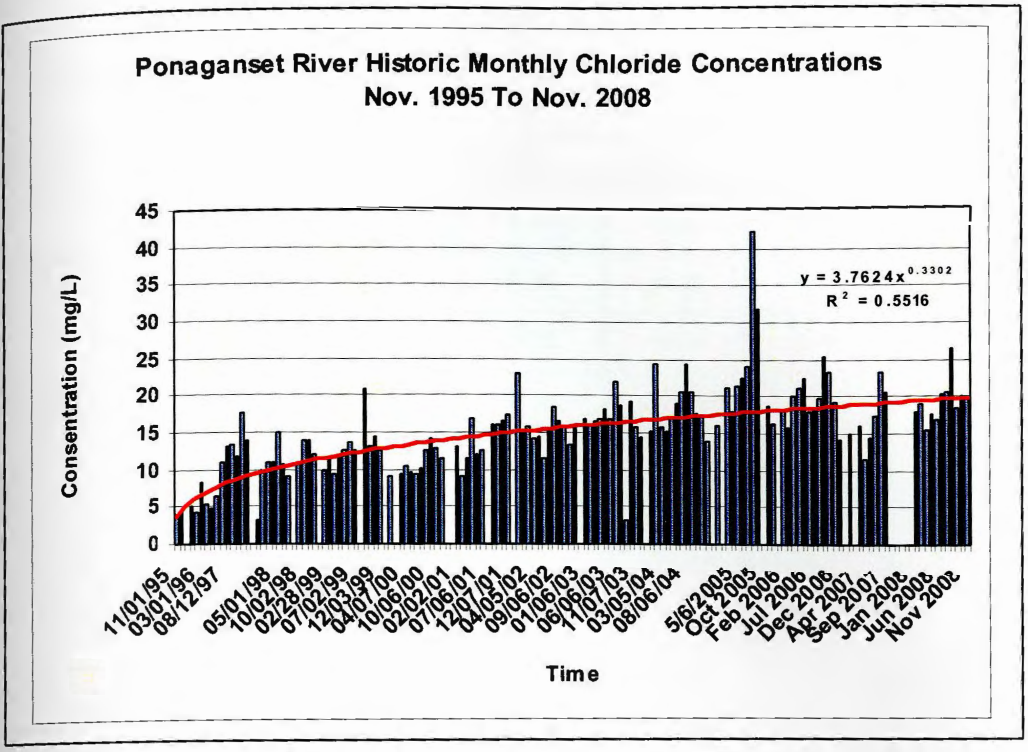


Figure 9.1: Summary of Historic PWSB Monthly DW Trends in Chloride Concentrations

Table 9.1: Summary of Trends for Historic PWSB Monthly Water Quality Data (November 1995 to November 2008)

Constituent	Units	Min.	Max.	Avg.
pH		5.40	7.00	6.70
Temperature	(Deg. C)	3.50	24.60	13.51
Acidity	(mg/L)	2.20	8.60	4.78
Total Alkalinity	(mg/L)	1.60	34.00	4.20
Color	(PtCo Units)	3	165	43
Chloride	(mg/L)	3.20	42.20	15.48
Turbidity	(ntu)	0.07	3.10	0.68
Nitrite	(mg/L)	0	0.020	0.002
Nitrate	(mg/L)	0	0.140	0.028
Total Phosphate	(mg/L)	0	0.47	0.07
Total Coliform	(100 ml)	0	2,400	340
E. Coli	(100 ml)	0	2,400	247
35C HPC Bacteria	(cfu/ml)	20	12,000	2,073

9.3 Total Coliform Bacteria

An important parameter used to determine the presence of microbial contamination is total coliform bacteria. Water in rivers and reservoirs commonly contains a variety of microorganisms which potentially could cause gastrointestinal illness in humans. Generally, the total-coliform group does not contain disease causing organisms but does indicate other potential pathogens such as sewage bacteria, protozoans (Giardia Lamblia and Cryptosporidium) and enteric viruses (Breault, Waldron, Barlow, and Dickerman 2000), all of which can cause disease in humans.

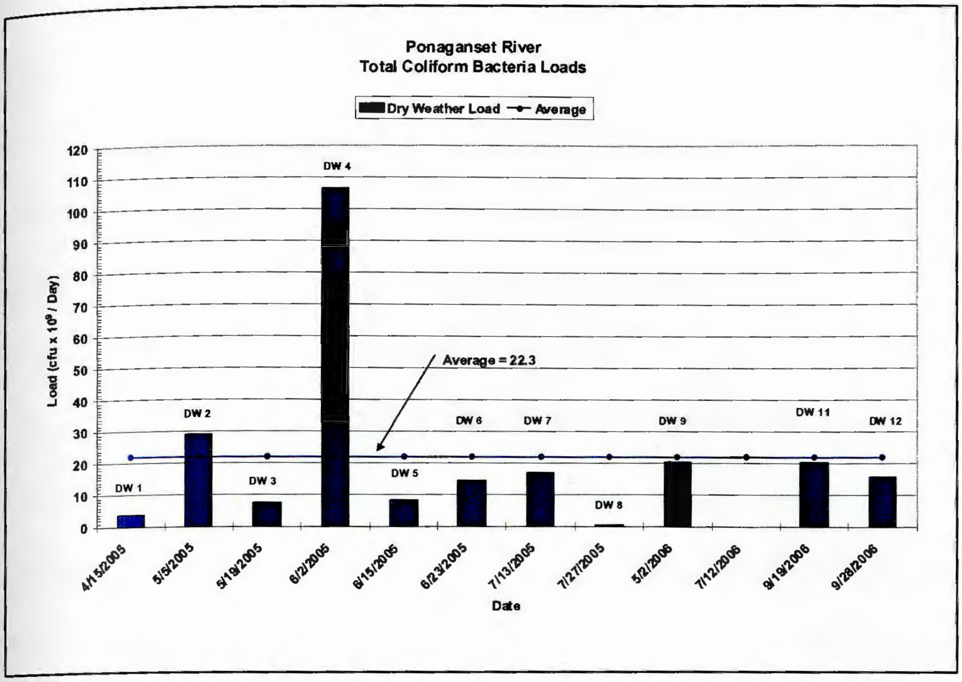
Historical PWSB data (Appendix E) for total coliform bacteria was reviewed for this site for the period from November 1995 through November

2008. The historic PWSB data cannot be compared to the analysis data due to differences in techniques used by the laboratories. Premier Laboratory uses the membrane filtration technique which is useful in monitoring drinking water and a variety of natural waters although, has limitations in water with high turbidity. Discussions with the PWSB laboratory staff (July 2009) have indicated that the highest total coliform bacteria counts typically occur during the months of August, September, and October. Historic PWSB trends observed for total coliform, indicated in Appendix E, identify the highest concentrations observed at the site occur in July and August while the lowest occurred in February through March. These variations in total coliform bacteria concentrations range from an average monthly concentration of 7 to 1,623 colonies per 100 ml. The lowest concentrations are the results of extended periods of cold water temperatures and the lack of vegetation growth while the opposite is true for the highest concentrations.

Loads and comparisons were made with total coliform bacteria to determine the basin characteristics, although data for this parameter was not complete. Of the twelve dry weather samples tested, eleven produced positive results. For the wet weather sampling, only storms one and three had sufficient data to determine wet weather loads. With only two data points, an equation could not be established for wet weather conditions. A partial data set of the dry weather loads was compared to the actual loads for WW 1 and WW3. The loads observed for WW 1 indicated 6.1×10^9 cfu (colony forming units) and for WW 3 was determined at 2.1×10^8 cfu for the entire storm. These actual loads were divided by the duration of the storms in days compared to eleven dry weather loads measured in billion colonies per day. The comparisons are described in Figure 9.2 and indicate that total coliform bacteria is wet weather driven in this sub-basin. Potential sources of bacteria could be runoff from roadways and other impervious areas, and leaching of aged septic systems.

Table 9.2: Summary of DW Total Coliform Bacteria Concentrations and Loads

Sample #	**Date**	**Discharge (cfs)**	**Water Temperature (Degrees C)**	**T. Coliform Bacteria (colonies/100 ml)**	**T. Coliform Bacteria (cfs x 10^9/day)**
1	4/15/05	25.50	10.31	6	3.74
2	5/5/05	34.00	11.56	35	29.12
3	5/19/05	16.00	14.34	19	7.44
4	6/2/05	20.75	16.23	210	106.63
5	6/15/05	4.43	20.55	80	8.67
6	6/23/05	3.72	19.08	160	14.56
7	7/13/05	3.51	22.51	200	17.18
8	7/27/05	0.98	26.19	20	0.48
9	5/2/06	12.00	11.38	70	20.55
10	7/12/06	14.00	22.88		
11	9/19/06	4.70	19.86	180	20.70
12	9/28/06	3.30	14.50	200	16.15
Max.			26.19	**210**	**106.63**
Min.			10.31	**6**	**0.48**
Avg.			17.45	**107**	**22.29**
Sta. Dev.				**83**	**29.18**



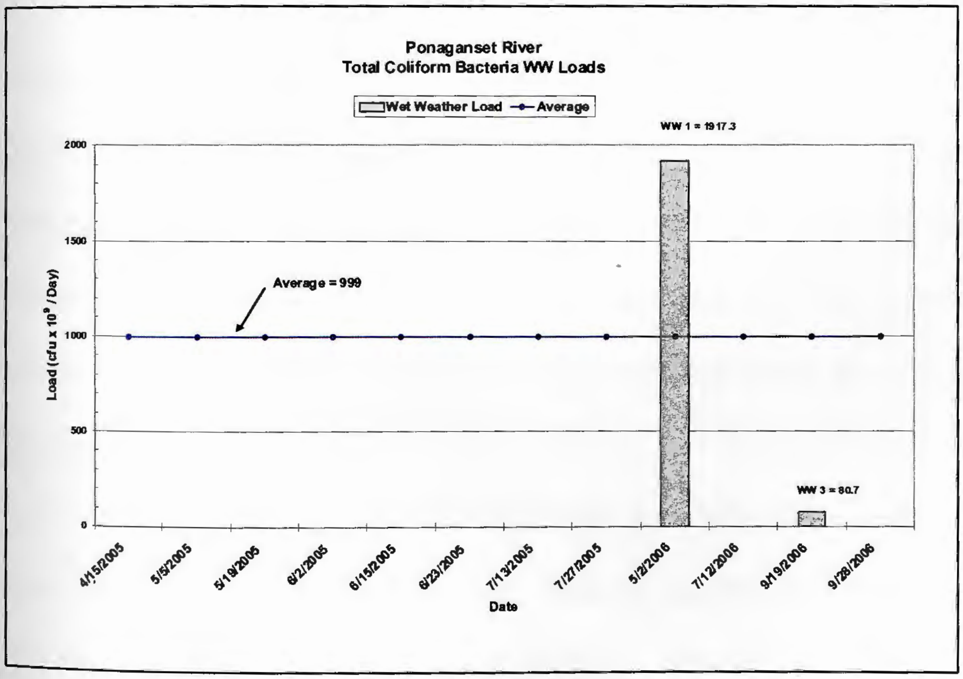


Figure: 9.2: Comparison of Dry and Wet Weather Loads for Total Coliform Bacteria April 2005 to September 2006

9.4 Direct Runoff and Annual Parameter Characteristics

The direct runoff of a storm is the result of excess rainfall for which the volume of rainfall excess and direct runoff should be equal. The unit hydrograph is the function that transforms the rainfall excess into the direct runoff for one inch of rainfall on the watershed (McCuen, 1998).

The total amount of annual direct runoff (cfs) at the Ponaganset River site during wet weather conditions based on 36 hydrographs averaged 2,140 cf, with an effective runoff depth of approximately 8.33 in. for the entire USGS fiscal year (October 1, 2003 To September 30, 2004). The 14.4 mi^2 drainage area surrounding the Ponaganset River site 01115187 has been monitored by USGS since 1994 to the present day for discharge and since 2000 to the current year for water quality data. The original project objective entailed determining an estimated percentage of dry versus wet weather load contribution at the site for a period of one year for selected constituents. This prediction cannot be made until further data is collected at the site, although the majority of load contributions at this site are dry weather driven. The wet weather characteristics determined at this site indicate partial determinations of loads for storms that fit the criteria of the analysis.

The Multiple Linear Regression (MLR) equations were solved using the least squares methodology which could only be partially predicted for storms evaluated during the course of this investigation. The project criteria indicated that water quality samples would be collected during the period of April through September, with at least a two day antecedent dry period, and at least 0.10 in. of total precipitation. After inserting the predicted MLR equations for all storms it was found that these equations could be applied to only a small portion of storms due to the number of storms collected and the project criteria for this analysis. The dry weather Linear Regression equations used to estimate the load for the entire year were summed for each constituent during base flow condition for the entire fiscal year is described in Appendix A.

9.5 Summary of Monthly Dry and Wet Weather Loads

The empirical equations described in chapter eight were applied to daily flow and precipitation data for a six month period occurring from April through September 2004. The discharge that occurred during this period is shown in Figure 9.2 and 9.3. Monthly load estimates shown in Table 9.2 identify that during periods of low precipitation amounts at the Ponaganset River sub-basin are primarily dry weather driven for May through July aside from manganese and aluminum in July 2004 which indicated loads being more wet weather driven during those months. In Table 9.2 the predicted load estimates for April, August, and September 2004 suggest that it is wet weather driven with the exception of

Table 9.3 Summary of 2004 Predicted Monthly Dry and Wet Weather Loads

Month	P_T (in.)	Type	Barium (lbs.)	Manganese (lbs.)	Aluminum (lbs.)	Sodium (lbs.)	Chloride (lbs.)
April	9.68	Dry	63.3	101.7	400.5	39,171	69,201
		Wet	152.7	56.1	312.2	57,840	144,600
		Total	216.0	157.8	712.7	97,011	213,801
May	2.78	Dry	37.8	59.4	229.8	24,194	42,824
		Wet	12.5	9.7	53.8	5,138	12,846
		Total	50.3	69.1	283.6	29,332	55,670
June	1.16	Dry	9.1	12.2	40.7	7,035	12,572
		Wet	1.1	0.9	3.3	424	1,060
		Total	10.2	13.1	44.0	7,459	13,632
July	2.46	Dry	3.1	2.4	3.4	3,434	6,223
		Wet	0	10.2	28.0	959	2,396
		Total	3.1	12.6	31.4	4,393	8,619
August	6.06	Dry	5.7	7.1	21.7	4,784	8,578
		Wet	9.7	70.2	226.6	7,192	17,981
		Total	15.4	77.3	248.3	11,976	26,559
September	5.25	Dry	10.0	13.4	45.9	7,735	13,825
		Wet	14.8	103.5	352.2	13,028	32,569
		Total	24.8	116.9	398.1	20,763	46,394
Total	27.39	Dry	129.0	196.2	742.0	86,353	153,223
		Wet	190.8	250.6	976.1	84,581	211,452
		Total	319.8	446.8	1,718.1	170,934	364,675

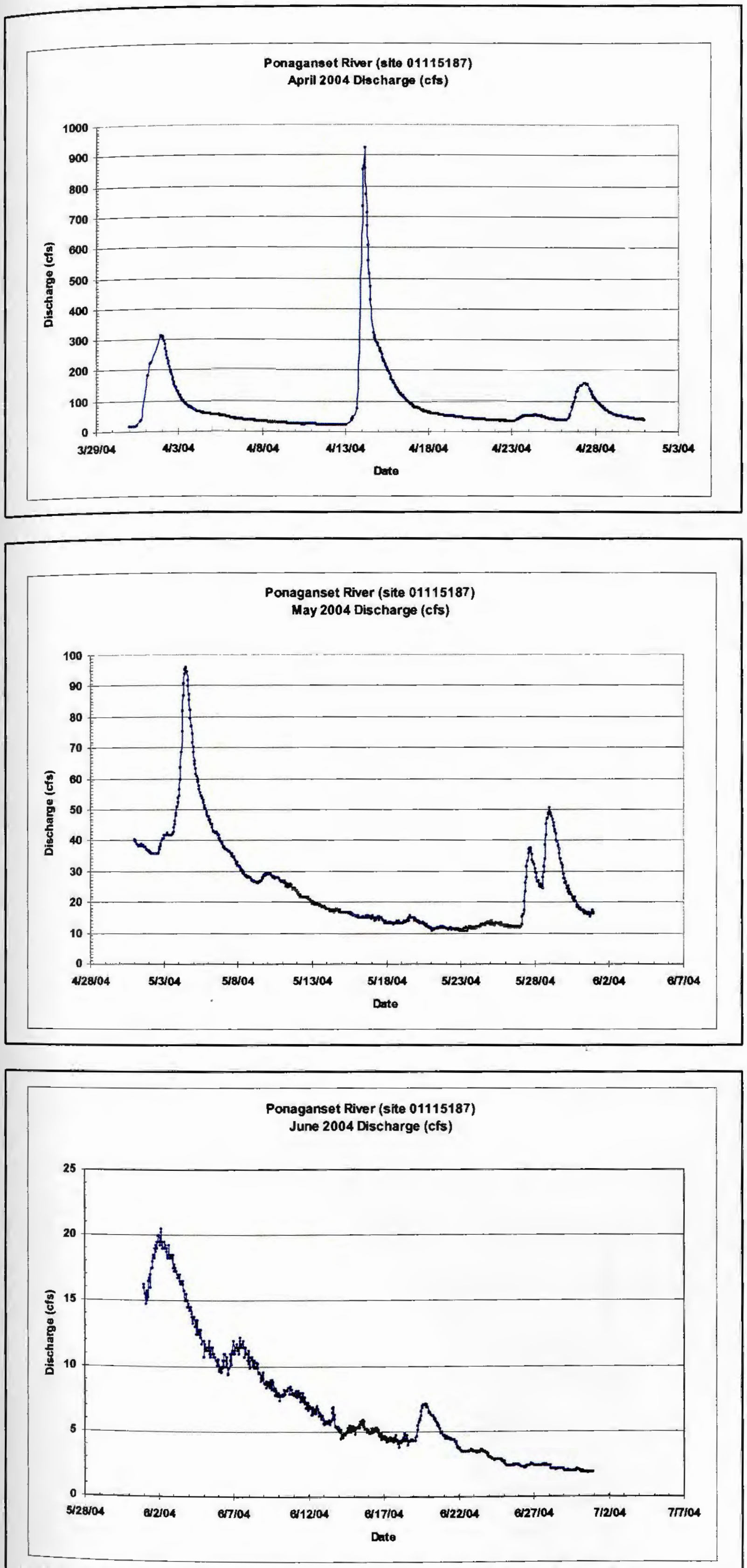
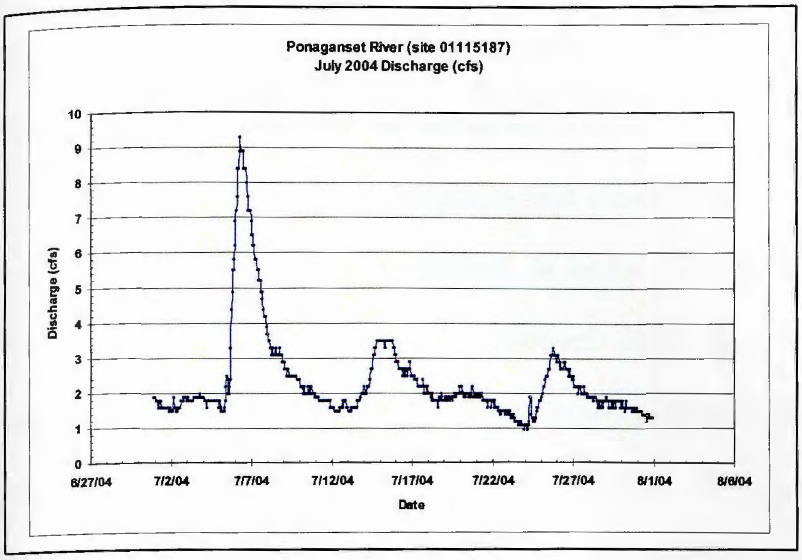
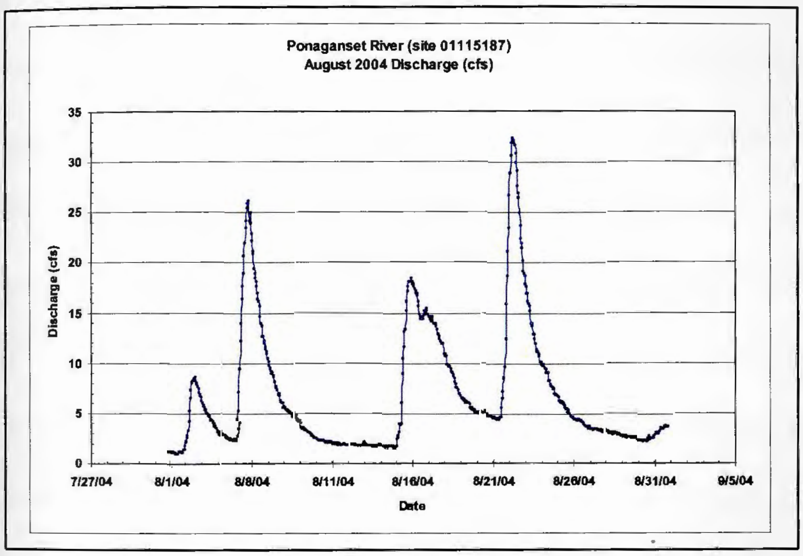


Figure 9.3: Ponaganset River April, May, and June 2004 Hourly Discharge





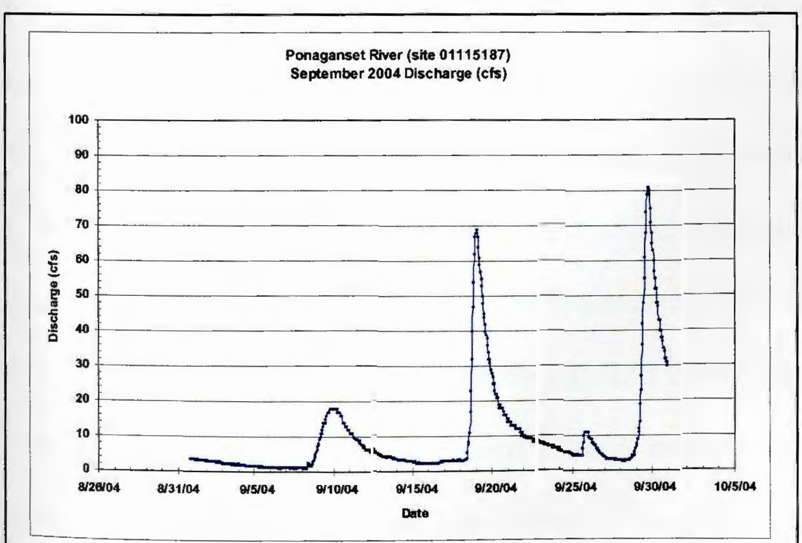


Figure 9.4: Ponaganset River July, August, and September 2004 Hourly Discharge

aluminum in April 2004 which may have resulted in excessive dilution from 9.68 in. of total rainfall that occurred during that month.

The application of data suggests that constituents should be monitored in both dry and wet weather conditions in order to establish a comprehensive monitoring program for the entire watershed. From observation of this data, it indicates that in the early spring and late summer / early fall periods are the best periods to monitor for wet weather on the watershed. The monthly data identifies that rainfall amounts in excess of five inches are primarily wet weather driven. If the Ponaganset River sub-watershed is wet weather driven (it is the most forested region), then it is expected that other sites (particularly in the eastern region of the Scituate Reservoir watershed due its greater population and lesser forested area) will be wet weather driven at even lower amounts of total monthly precipitation.

USGS Report 2008-5060 performed by (Nimiroski, DeSimone, and Waldron, 2008), studied load trends on the Scituate Reservoir during dry weather, which evaluated loads at 37 water quality sites on the entire watershed. The study indicates that the Ponaganset River site and downstream of Barden Reservoir have the largest mean discharge and the largest loads for total coliform bacteria, E. coli bacteria, chloride, iron, and manganese. Other studies performed by (Yeboah and Wright, 1999) determined water quality conditions in the Saugatucket River during both dry and wet weather conditions. In this study, it was found that during dry weather the area around the old mill complex in Peace Dale, South Kingston is a major source of fecal coliform bacteria. In addition, ammonia and nitrate was a significant source to the river. Ammonia and nitrate loads were generated based upon three wet weather events and dry weather data much like this analysis and determined annual load estimates for the year. During wet weather, results were similar to dry weather. Aside from runoff and resuspension, there was a general increase in loads for trace metals that indicated trace metal violations.

The "Blackstone River Wet Weather Initiative" water quality program was written by Wright, Chaudhury, and Makam in 1989-1990, and determined dry and wet weather conditions and pinpointed and ranked sources of pollutants to the river. In this study the wet weather component attempted to establish loads from point and non-point sources as well as old materials from the resuspension from sediment from the bottom of the river. Methods of determining annual wet loads using rainfall characteristics were described in this analysis, and was followed for future wet weather monitoring at the Ponaganset River basin and the entire Scituate Reservoir watershed in chapter 10.

9.6 Summary of Dry and Wet Weather Annual Loads

Concentrations are useful in determining water quality criteria, although constituent loads assist in determining the chemical mass transported by the Ponaganset River at this particular site at the specified time. To determine the annual based loading for selected constituents involved the prediction of linear regression (LR) and multiple linear regression equations (MLR), this is discussed in detail in Chapter 8. The records evaluated for Fiscal 2003 produced 42 initial hydrographs for storms that occurred during this year. The average daily discharge rates that occurred from October 1, 2003 to September 30, 2004 on the Ponaganset River is illustrated in Figure 9.6 for both dry and wet weather conditions at the site. A total of 94 storms were determined for this year which equates to 177 days of wet weather. The total amount of precipitation for these 94 storms ranged from 0.01 to 4.62 in. of total precipitation which was determined from records collected from the USGS's precipitation gauge at the Ponaganset River site. From this data only, a small portion of storms that occurred could be utilized to determine wet weather loads estimates due to the field data collected for this analysis and the project criteria. Storms with characteristic properties as those from the evaluation identify a reasonable accuracy between the results. The probability of exceedence ranged from 13% to 31 % (Figure 9.5) for the storms collected for this analysis in relation to the Fiscal 2003 data. These storms have a range of total precipitation of 0.45 in. to 1.38 in. and maximum discharge minus base flows that range from 7.5 cfs to 88 cfs. The analysis storms fall within an acceptable range in comparison to the storms evaluated in Fiscal 2003. A partial estimate of wet weather loads for the six constituents is identified in Table 9.4 based on these storms:

Table 9.4: Partial Summary of Predicted WW Loads 2004

Date	ADP (days)	P_T (in)	$Q_{MAX} - Q_B$ (cfs)	Barium (lbs.)	Manganese (lbs.)	Aluminum (lbs.)	Iron (lbs.)	Sodium (lbs.)	Chloride (lbs.)
6/1-3/2004	3.4	0.50	4.50	0.22	1.64	3.99	32.02	347.13	520.70
7/24/2004	5.0	0.53	3.20	0.10	2.62	6.64	54.70	363.67	545.51
7/5/2004	3.0	0.70	7.57	0.72	6.79	20.51	121.77	1106.37	1659.56
5/28/2004	1.2	0.73	25.75	2.75	5.44	21.21	42.38	2200.03	3300.04
8/21-22/04	4.8	0.90	27.95	3.14	9.87	35.30	120.81	2822.74	4234.11
5/2-4/2004	5.0	0.91	53.50	5.95	7.08	33.59	-7.78	4264.96	6397.44
4/26-28/2004	2.0	1.38	126.50	14.39	11.29	65.84	-141.58	9686.68	14530.02
Max.				1.38	126.50	65.84	121.77	9,686.68	14,530.02
Min.				0.10	1.64	3.99	-141.58	347.13	520.70

For dry weather conditions annual loads were determined for the entire year. To do this, hydrograph data had to be separated from the base flow, while the average daily discharge was used during dry days. The results of the annual dry weather loads estimated for this analysis are identified in Table 9.5 below from smallest to largest load in lbs./yr.:

Table 9.5: Summary of Annual Predicted DW Loads (lbs./yr.)
October 1, 2003 To September 30, 2004

Constituents	Load (lbs./yr.)
Barium	282
Manganese	437
Aluminum	1,671
Iron	4,121
Sodium	184,320
Chloride	326,615

* Estimated loads based on 189 days of dry weather.

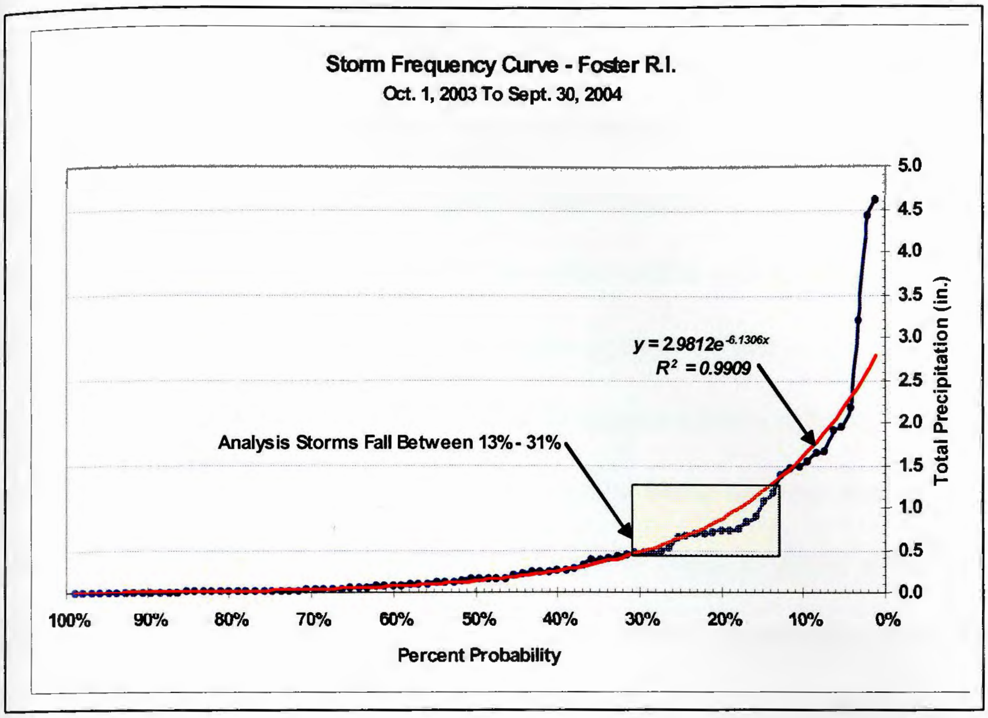


Figure 9.5: Storm Frequency Curve – Foster R.I. (October 1, 2003 to September 30, 2004)

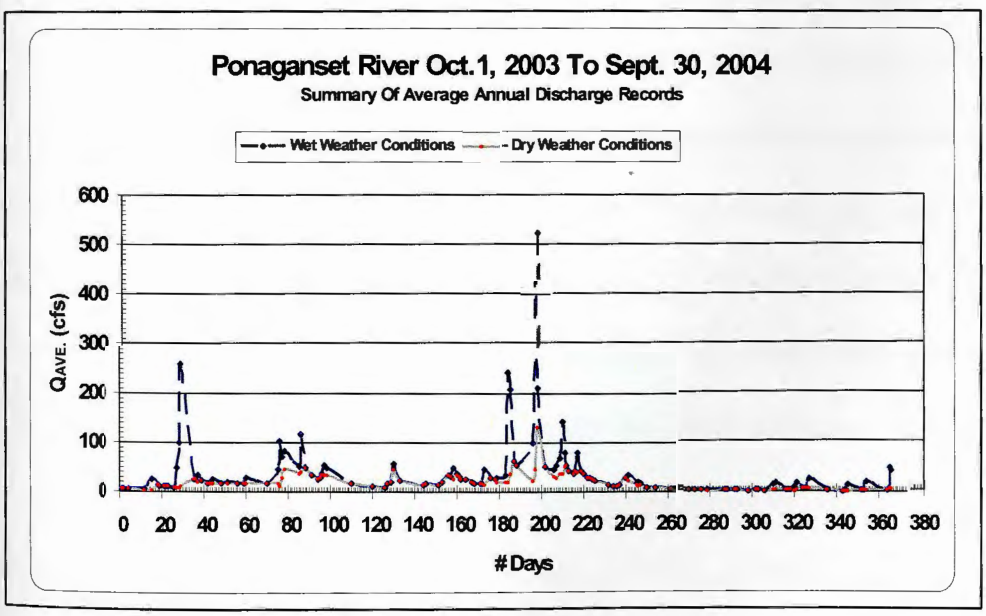


Figure 9.6: Annual Average Day Dry and Wet Weather Discharge Rates (October 1, 2003 to September 30, 2004)

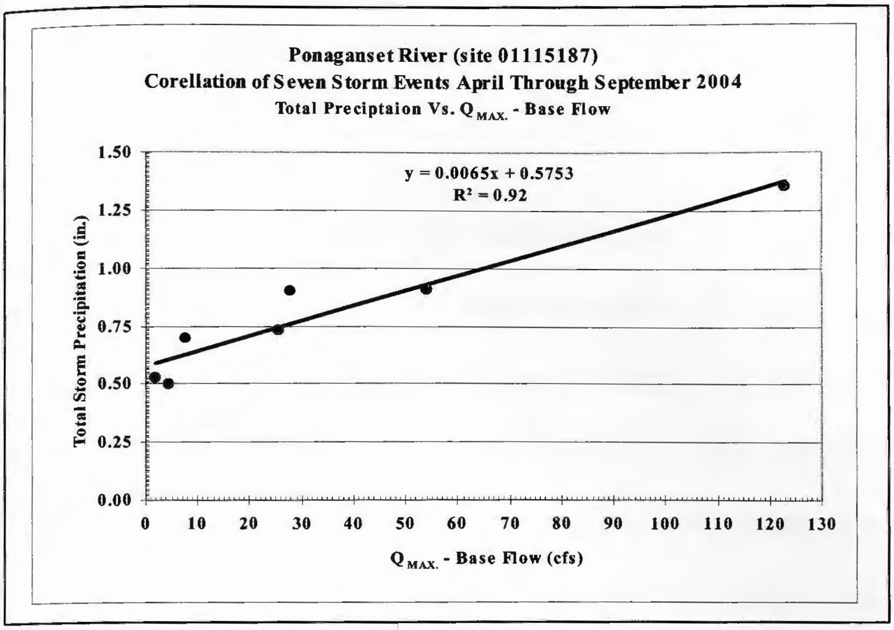
9.7 Summary of Results

The results of the annual analysis data indicate estimated loads in (lbs. / day) during dry weather conditions and (lbs.) for partial wet weather contributions over a period of one year's worth data from October 1, 2003 to September 30, 2004. The MLR equations applied to the wet weather conditions at this site were found to be the most difficult and complex portion of this analysis. The MLR models used for this period of data indicated negative loads, although it is obvious that they cannot decrease below zero. Typically, loads increase accordingly until reaching a maximum load then either level out or begin to dilute with increasing discharge rates. The summary of load characteristics associated with these six constituents for this period of record are described in Figure 9.4 for both dry and wet weather conditions. The predicted dry weather loads are based upon 189 days of record using average daily discharge (cfs). The ranges of results predicted during dry weather for this 189 day period are summarized in Table 9.3 for the six constituents reviewed for the dry weather analysis. In addition, graphs indicated in Figure 9.2 may be used to determine expected loads, based upon the average daily discharge measurement at the site used in conjunction with the predicted dry weather linear regression models. The wet weather load characteristics are based on seven storms that occurred between April through September 2004. These seven storms were the only ones that could be compared to the analysis storms collected in 2006 for the analysis. In addition, MLR equations for sodium and iron could not be used due to irregularities in the analysis of Storm 2 data which appeared to only affect these two constituents. The predicted loads for sodium was estimated in terms of chloride or 40% of what was predicted for chloride based upon the fact that NaCl and $CaCl_2$ enter the watershed from road salting during the winter months.

Table 9.6: Predicted DW and WW Load Trends (October 1, 2003 To September 30, 2004)

	Predicted Dry Weather Load (lbs./day)			Predicted Wet Weather Load (lbs.)		
	Max.	**Min.**	**Ave.**	**Max.**	**Min.**	**Ave.**
Barium	6.67	0.07	1.49	14.39	0.10	3.83
Manganese	10.78	-0.02	2.31	11.29	1.64	6.38
Aluminum	42.69	-0.48	8.84	65.84	3.99	26.54
Iron	74.21	7.38	21.80	121.77	-141.58	33.41
Sodium	4,075.90	121.67	975.24	9686.68	347.13	2,928.39
Chloride	7,196.02	222.89	1,728.12	14,530.02	520.70	4,392.59

The characteristics associated with the independent variables used for the wet weather MLR equations (Total precipitation (in.) and $Q_{MAX.}$ – Base Flow) were compared for the three analysis storms and the seven storms taken from the annual parameter data. In these comparisons shown in Figure 9.5 both indicate a high R^2 correlation (92 % (2004) and 99% (2006)) which indicates that the predictive factors used in the MLR equations are valid for predicting wet weather conditions in the watershed.



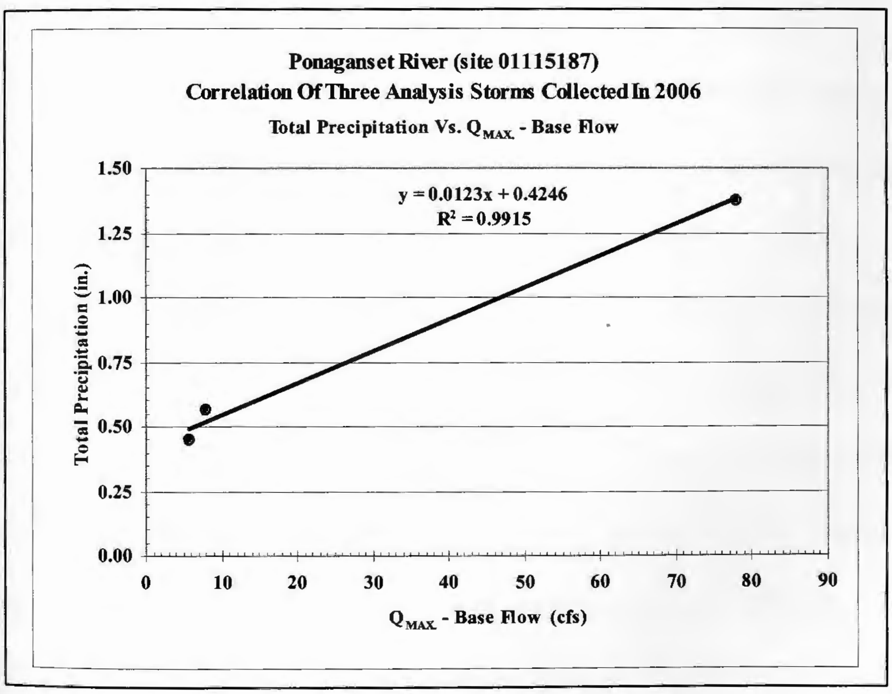


Figure 9.7: Comparison of MLR Variables - Annual versus Analysis Data

CHAPTER 10

10 SUMMARY AND RECOMMENDATIONS

10.1 Summary

A field investigation was performed at the Ponaganset River site 01115187 between April 2005 and September 2006. The purpose of this analysis was to establish a preliminary wet weather monitoring program to determine pollutant loads contributed by stormwater runoff. The investigation involved collection of enough data to conduct a study of constituent concentrations, instantaneous loads, and predicted load estimates during dry and wet weather deposition. During the first phase, eight dry weather samples were collected on a biweekly basis between April through August 2005. On July 27, 2005, it was decided to discontinue sampling for the remainder of the year due to drought like conditions and recommence sampling in April 2006 when four additional samples were collected. Three wet weather events were sampled in 2006.

A total of thirty two parameters were initially tested, although only fifteen were observed at the site. Metals that were consistently observed include: barium, manganese, aluminum, iron, and sodium. Other parameters include: copper, acidity, alkalinity, turbidity, color, pH, total suspended solids, ammonia, chloride, and total coliform bacteria. Total coliform bacteria was also considered for this evaluation but the data for this parameter was insufficient to correlate a predictive load equation.

The results of this investigation suggested six predicted dry weather linear regression models that were generated from twelve sample events collected at the site. The linear regression models use instantaneous loads to develop a relationship using the river's discharge to predict the load in pounds per day. Wet weather loads were predicted using six multiple linear regression models using maximum discharge minus the baseflow and total precipitation as the independent variables. Other independent variables attempted in the MLR models (i.e., specific conductance, intensity) were not successful. The precipitation characteristics of the three storms that were evaluated ranged from 0.45 in. to 1.38 in. (Table 6.1). Storms that are larger or smaller can not be accurately predicted without further collections of storm data. Load estimates generated using developed MLR equations proved to predict loads for barium, manganese, aluminum, and chloride. Sodium and iron could not be accurately modeled due to skewed results from storm two. Predicted MLR equations applied to the annual parameter data indicated negative loads for storms less than 0.45 in. of total precipitation and extremely large predicted values for storms greater than 1.38 in. of total precipitation. Sodium load estimates were determined based upon forty percent of the predicted chloride load. The percentage of sodium was derived based upon the molar concentration in road salt used on roadways throughout the Scituate Reservoir watershed.

Other factors which influence the water quality conditions at this site are bedrock geology, land use, land slope, road salting, and leaching from septic systems. The bedrock geology consists of augen granite-gneiss with alkali-feldspar porphyroclasts from which barium, manganese, and iron can be derived. The iron detected at the site may be present from natural deposits, sanding of roadways, moving engine parts, and auto body rust. The USGS has indicated that "the drainage basin characteristics explain at least 50 percent of the variability in concentrations of water quality constituents" (Breault, Waldron, Barlow, and Dickerman, 2000). Barium levels are relatively consistent with little to no variation under wet or dry weather conditions. Concentrations ranged from 0.013 to 0.021 mg/L during dry weather conditions. The largest loads observed at the site indicated 3.48 lbs./day during dry weather and 9.2 lbs. for wet weather. Barium is considered a minor pollutant although the USEPA considers this parameter important and requires testing for drinking water and providing this data in the Consumer Confidence Report (CCR) which is distributed to PWSB consumers. Iron showed concentrations higher than the USEPA 0.30 mg/L SMCL at lower flow rates observed in fifty percent of the dry weather samples and two out of three storm events. Manganese indicated four out of twelve dry weather samples above the SMCL and only one wet weather sample was detected greater than the USPEA SMCL of 0.05 mg/L (U.S. Environmental Protection Agency, 2005 NSMCL). Previous studies commissioned by USGS (Breault, Waldron, Barlow, and Dickerman, 2000) have indicated that the Ponaganset River sub basin had the smallest constituent concentrations than all the other sub basins in the Scituate Reservoir watershed with the exception of orthophosphate and manganese near the spillway of the Ponaganset Reservoir. In this analysis, dissolved orthophosphate was measured although laboratory results did not detect any traces at site 01115187. Manganese was present throughout this investigation and used for the analysis evaluation.

The most important nonpoint source pollutants determined in this analysis were sodium and chloride. These potential sources have been discussed in several publications such as Runge (1989), USGS, and others, and include sodium chloride used as a deicing agent on local roadways, highways, parking lots, and sidewalks within the Scituate Reservoir watershed. The U.S. Environmental Protection Agency recommends that sodium concentrations do not exceed 20 mg/L in drinking water (U.S. Environmental Protection Agency, 2005 NPMCL). The National secondary drinking water standard for chloride is 250 mg/L (U.S. Environmental Protection Agency, 2005 NSMCL). Analysis results indicated that sodium reached a maximum of 17 mg/L and chloride reached 27 mg/L during dry weather conditions at a flow of 3.3 cfs. During wet weather conditions sodium concentrations reached their highest concentration of 15 mg/L and chloride reached 26 mg/L during the third wet weather event collected for this analysis. In fact, sodium and chloride showed a decrease in concentrations during wet weather. This is due to dilution of these constituents because sodium and chloride dissolve in the river. Aside from the fact that concentrations decreased during wet weather, loads increased due to large river flow rates. Throughout this entire analysis the concentrations sodium and chloride were less than the USEPA SMCL.

In the future, areas of denser land use within the watershed may require additional sampling and more frequent testing. It is recommended that PWSB should consider the installation of real-time monitoring equipment at a few important site locations that currently have only a staff gauge. In addition, real-time precipitation gauges would be ideal to replace the five existing rain gauges situated throughout the entire watershed and install one new rain gauge at the Providence Water Treatment Plant in Scituate Rhode Island.

The following recommendations are offered to establish long term patterns of instantaneous loads for PWSB:

- Record staff gauge height or discharge at the time the sample is collected.
- Determine precise date and time samples are collected.
- Record antecedent dry period.
- Specific constituents such as sodium, iron, manganese, and aluminum should be collected and tested on a monthly instead of quarterly basis in addition to currently tested water quality parameters.
- Analysis of barium and other minor pollutants could be limited in extent.
- Consider testing for both dissolved and total metal concentrations.

Since 1945 PWSB has been testing for pH, color, turbidity, total coliform bacteria, acidity, alkalinity, iron, and manganese on the watershed. In 2009, PWSB continues to collect and test samples on a monthly and or quarterly basis at 35 sites throughout the Scituate Reservoir watershed. In the future, water quality will be of greater concern with more stringent regulations. As additional commercial buildings are constructed and vehicle transport increases throughout the watershed, water quality monitoring should continue to increase as well. This analysis identified how loads estimation can be used to develop long term characteristics. These water quality characteristics can be used to determine the contribution of dead storage to tributaries such as Barden Reservoir in the case of this analysis or be used to develop a full scale wet weather analyses on the entire Scituate Reservoir Watershed.

10.2 Procedure for Future Development of Annual Loads

The following suggestions are being offered from the results of this analysis to be able to determine annual load contributions associated with the Ponaganset River site.

- Continue collection of samples with modification to the water quality program developed for this site.
  - Minimum Total Precipitation = 0.25 in.
  - Minimum Antecedent Dry Period = 2.5 days
- Collect a few more storms between 0.25 in and 0.45 in. of total precipitation and storms that are greater than 1.38 in. of total precipitation.
- Collect additional dry weather samples for the same constituent identified in this analysis at different seasons with a minimum 2.5 day antecedent dry period.
- Develop or use hydrograph data for a minimum of one year.
- Separate dry days and individual storm events for that year.
- Using the independent variables $Q_{AVE.}$ for dry weather and $Q_{MAX.-BF}$ and P_T for wet weather, determine loads using developed linear and multiple linear regression models for constituents identified in the analysis.

This will provide an annual percentage of loads contributed for both dry and weather deposition for a years worth of data for this site.

10.3 Future Wet Weather Monitoring on the Scituate Reservoir Watershed

In the future, wet weather monitoring on the Scituate Reservoir Watershed should consist of the following:

- Collection of wet weather samples at 3 or 4 sub-watersheds within the Scituate Reservoir Watershed limits.
- Research water quality, discharge, and precipitation data for each selected site
- Develop a water quality program for monitoring the selected sites consisting of the following
    - Period of Sampling
    - Minimum Antecedent Dry Period
    - Minimum Total Precipitation
    - Minimum number of storms to be evaluated
- Determine the type of constituents to be evaluated for all sites
- Determine an estimated number of samples to be collected during wet weather sampling to be able to determine the entire hydrograph for each storm.

Once this is established follow the same procedures used in this analysis to develop a comprehensive wet weather evaluation of the entire Scituate Reservoir Watershed.

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APPENDIX A

List of Equations

Predicted Linear Regression Models For Dry Weather Conditions

(1) Barium

$y = 0.1018 * (\text{Discharge}) - 0.0527$ $R^2 = 98.59$ % Confidence Level

(2) Manganese

$y = 0.01666 * (\text{Discharge}) - 0.2183$ $R^2 = 90.94$ % Confidence Level

(3) Aluminum

$y = 0.6662 * (\text{Discharge}) - 1.2782$ $R^2 = 95.64$ % Confidence Level

(4) Iron

$y = 1.0314 * (\text{Discharge}) + 6.1381$ $R^2 = 72.39$ % Confidence Level

(5) Sodium

$y = 61.022 * (\text{Discharge}) + 48.445$ $R^2 = 97.30$ % Confidence Level

(6) Chloride

$y = 107.61 * (\text{Discharge}) + 93.761$ $R^2 = 98.91$ % Confidence Level

Where,

Discharge = Average Hourly Discharge (cfs)

Predicted Wet Weather Multiple Linear Regression Equations

(7) Barium

y = 0.86 * (Total Precipitation) + 0.11 * (Peak Discharge – Base Flow) – 0.71

(8) Manganese

y = 27.60 * (Total Precipitation) - 0.12 * (Peak Discharge – Base Flow) – 11.62

(9) Aluminum

y = 84.15 * (Total Precipitation) – 0.10 * (Peak Discharge – Base Flow) – 37.64

(10) Iron

Unable to predict WW loads

(11) Sodium

Based Upon 40% of the predicted Chloride Load

(12) Chloride

y = 4421.19 * (Total Precipitation) + 82.94 * (Peak Discharge – Base Flow) – 2063.13

Where,

Total Precipitation (in.)

Peak Discharge – Base Flow (cfs)

APPENDIX B

List of Symbols

Unit Hydrograph Data

P_n	=	effective precipitation or runoff depth of the storm
K	=	conversion constant
V	=	volume under the hydrograph
A	=	drainage area of the basin

Load Determination

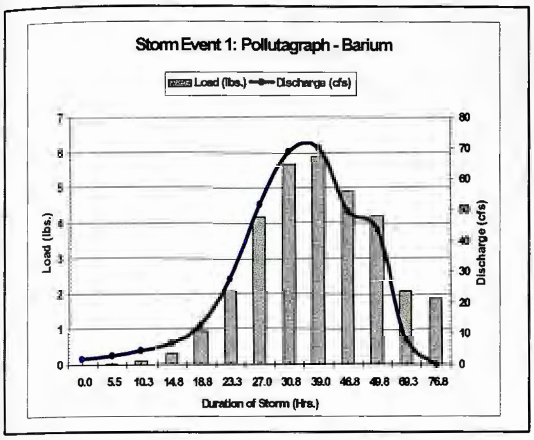
$W = Ku*Q*C$

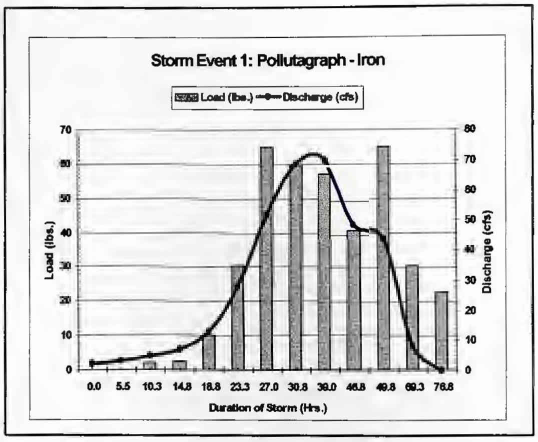
Where,

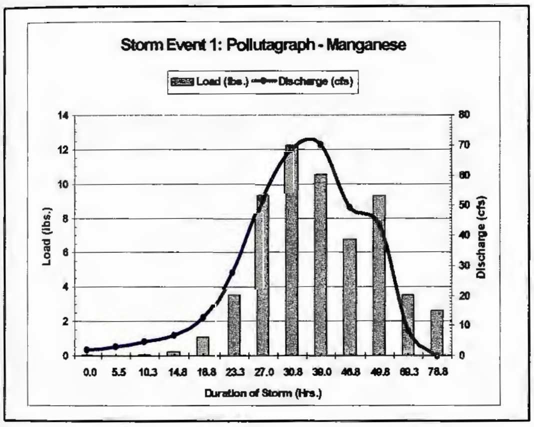
W	=	load (lb/day)
Ku	=	conversion constant (5.39)
Q	=	discharge (cfs)
C	=	constituent concentration (mg/L)

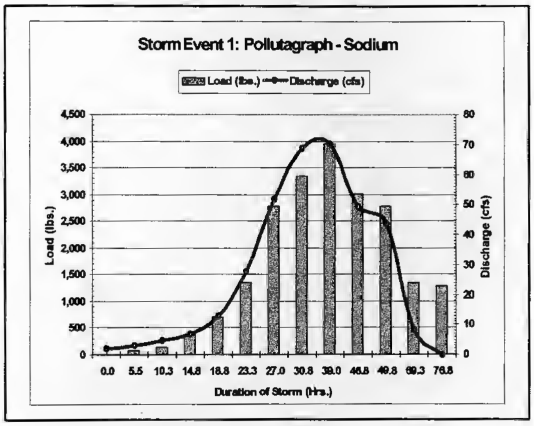
APPENDIX C

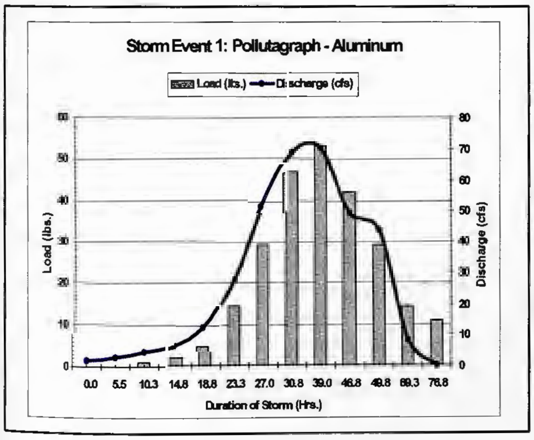
WW Pollutagraphs Storms 1 – 3

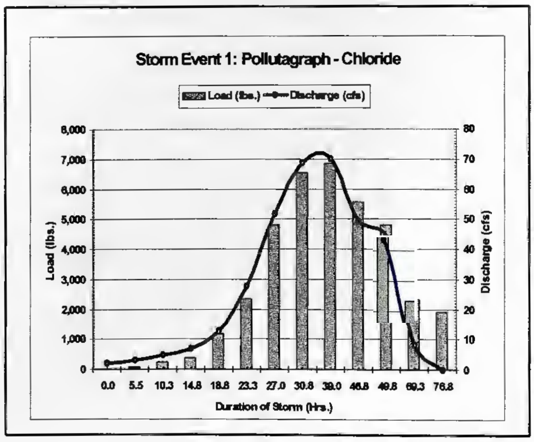


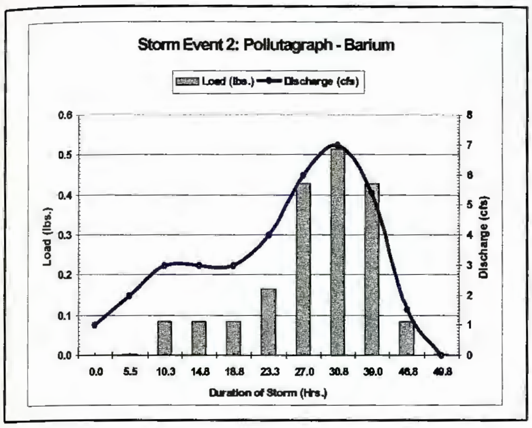


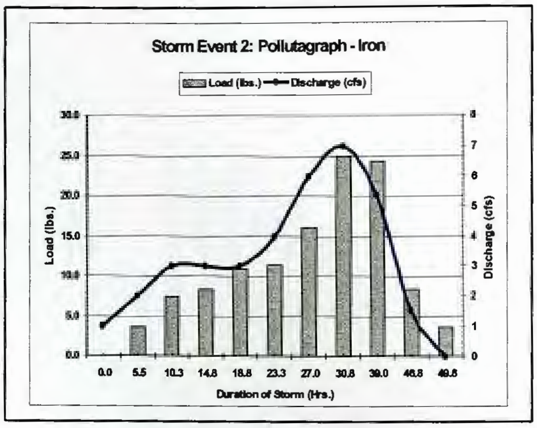


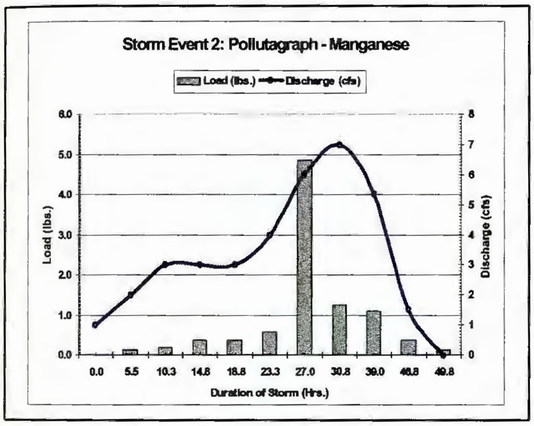


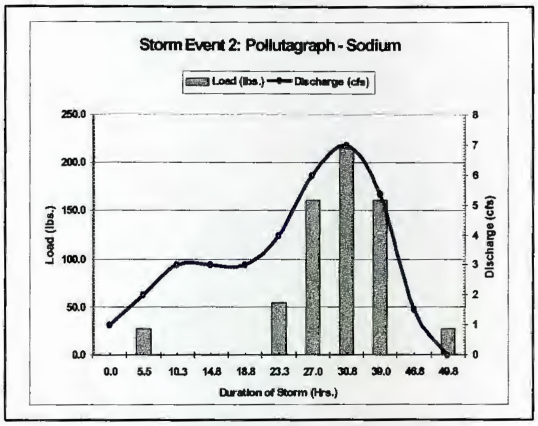


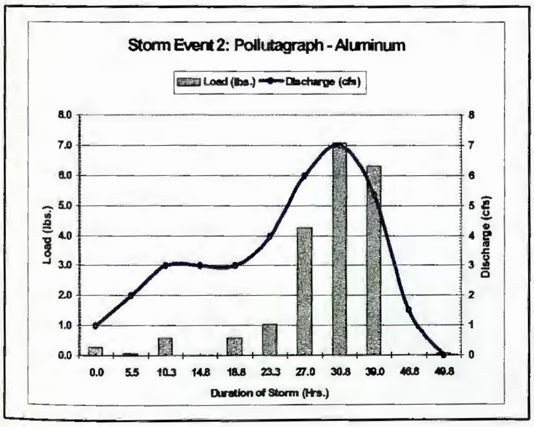


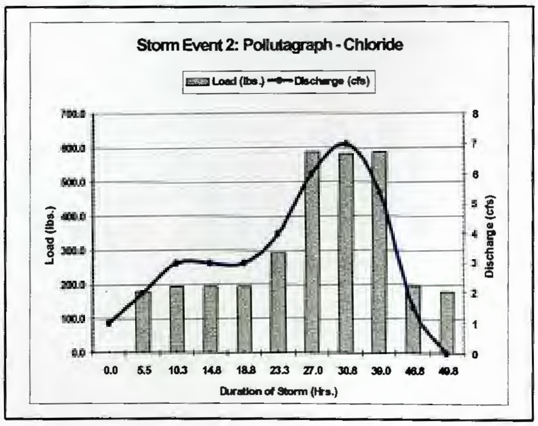

Storm Event 2: Pollutagraph - Barium
Load (lbs.) Discharge (cfs)
Load (lbs.)
Discharge (cfs)
Duration of Storm (Hrs.)

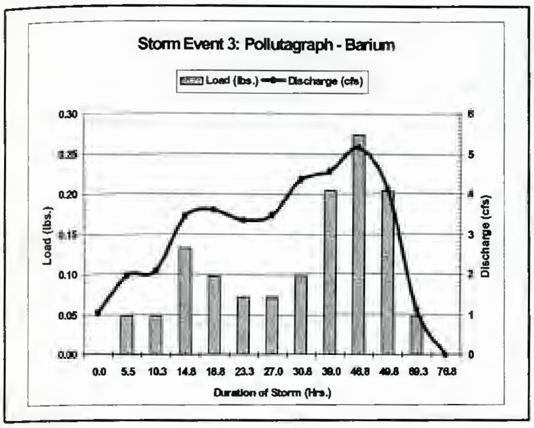

Storm Event 2: Pollutagraph - Iron
Load (lbs.) Discharge (cfs)
Load (lbs.)
Discharge (cfs)
Duration of Storm (Hrs.)

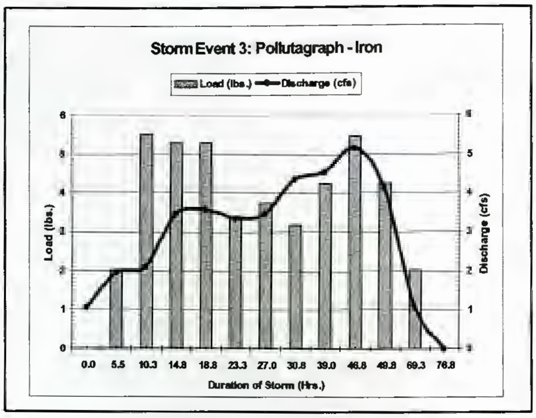

Storm Event 2: Pollutagraph - Manganese
Load (lbs.) Discharge (cfs)
Load (lbs.)
Discharge (cfs)
Duration of Storm (Hrs.)

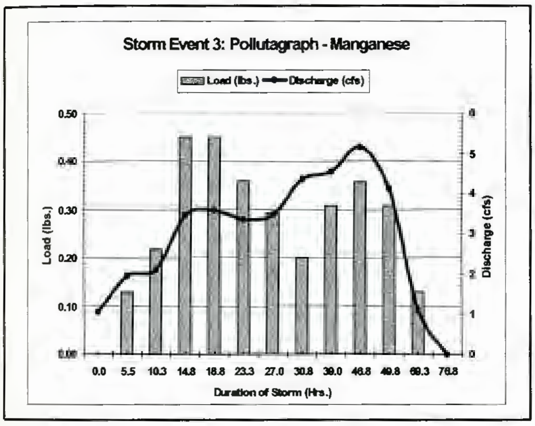

Storm Event 2: Pollutagraph - Sodium
Load (lbs.) Discharge (cfs)
Load (lbs.)
Discharge (cfs)
Duration of Storm (Hrs.)

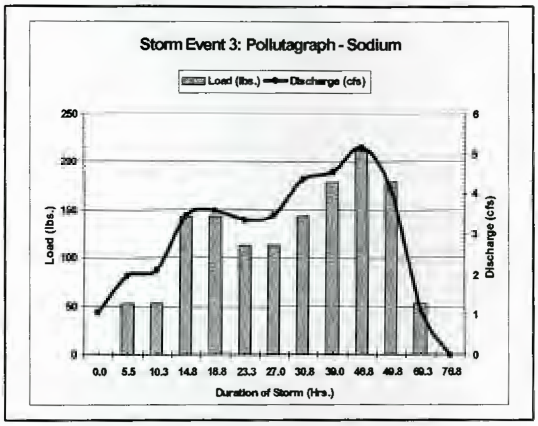

Storm Event 2: Pollutagraph - Aluminum
Load (lbs.) Discharge (cfs)
Load (lbs.)
Discharge (cfs)
Duration of Storm (Hrs.)

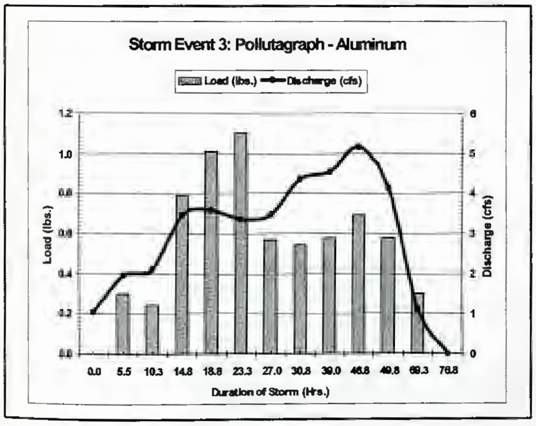

Storm Event 2: Pollutagraph - Chloride
Load (lbs.) Discharge (cfs)
Load (lbs.)
Discharge (cfs)
Duration of Storm (Hrs.)

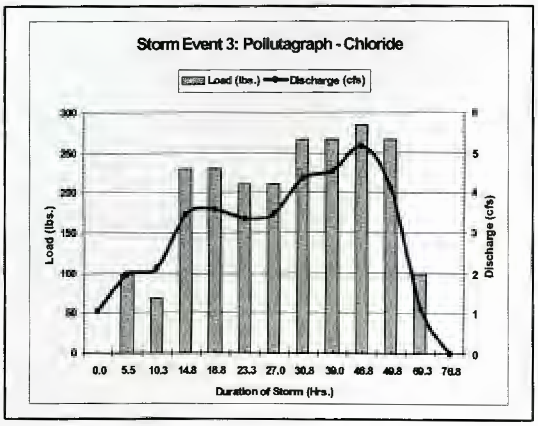

Storm Event 3: Pollutagraph - Barium
Load (lbs.)
Discharge (cfs)
0.00 0.05 0.10 0.15 0.20 0.25 0.30
0 1 2 3 4 5 6
0.0 5.5 10.3 14.8 18.8 23.3 27.0 30.8 39.0 46.8 49.8 69.3 76.8
Duration of Storm (Hrs.)


Storm Event 3: Pollutagraph - Iron
Load (lbs.)
Discharge (cfs)
0.0 5.5 10.3 14.8 18.8 23.3 27.0 30.8 39.0 46.8 49.8 69.3 76.8
Duration of Storm (Hrs.)


Storm Event 3: Pollutagraph - Manganese
Load (lbs.)
Discharge (cfs)
0.10 0.20 0.30 0.50
0 1 2 3 4 5 6
0.0 5.5 10.3 14.8 18.8 23.3 27.0 30.8 39.0 46.8 49.8 69.3 76.8
Duration of Storm (Hrs.)

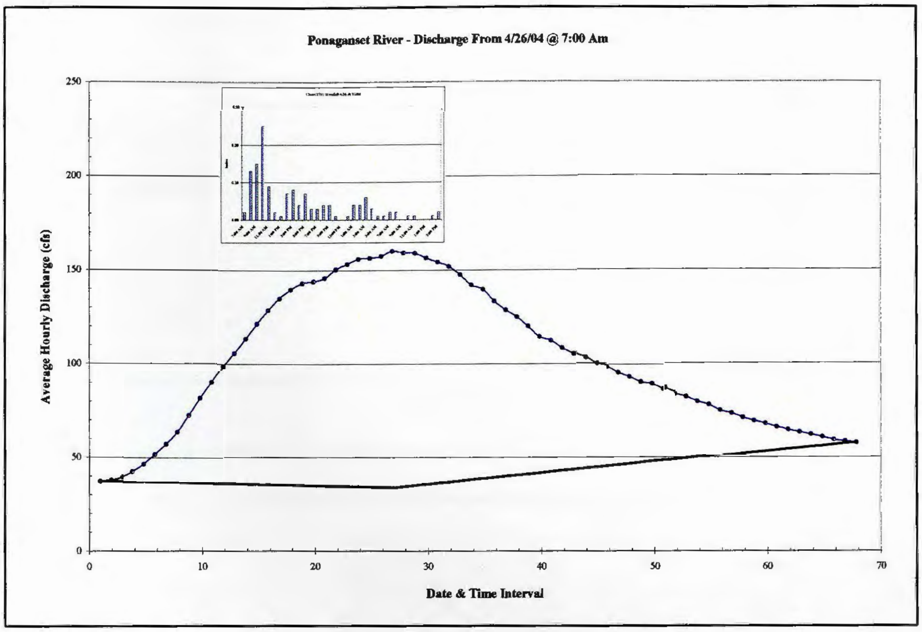

Storm Event 3: Pollutagraph - Sodium
Load (lbs.)
Discharge (cfs)
0 50 100 150 250
0 1 2 3 4 6
0.0 5.5 10.3 14.8 18.8 23.3 27.0 30.8 39.0 46.8 49.8 69.3 76.8
Duration of Storm (Hrs.)

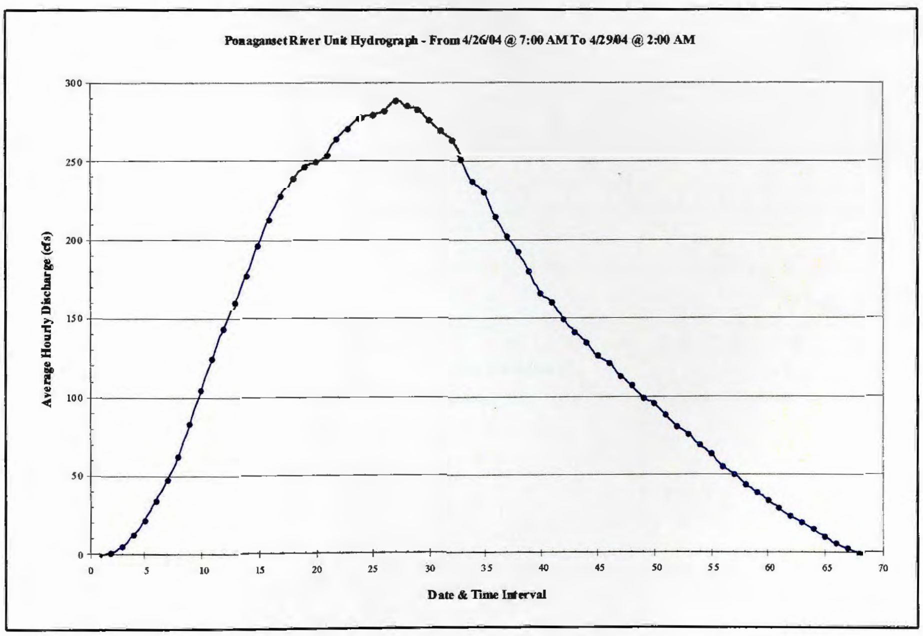

Storm Event 3: Pollutagraph - Aluminum
Load (lbs.)
Discharge (cfs)
0.4 1.0 1.2
0 1 2 3 4 5 6
0.0 5.5 10.3 14.8 18.8 23.3 27.0 30.8 39.0 46.8 49.8 69.3 76.8
Duration of Storm (Hrs.)

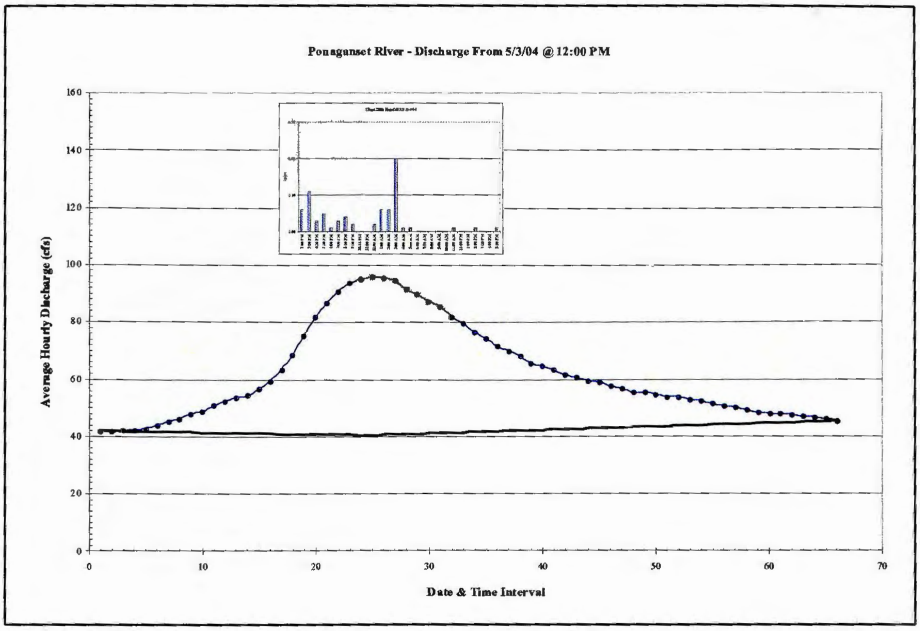

Storm Event 3: Pollutagraph - Chloride
Load (lbs.)
Discharge (cfs)
0 50 100 150 200 250 300
0 1 2 3 4 5
0.0 5.5 10.3 14.8 18.8 23.3 27.0 30.8 39.0 46.8 49.8 69.3 76.8
Duration of Storm (Hrs.)

APPENDIX D

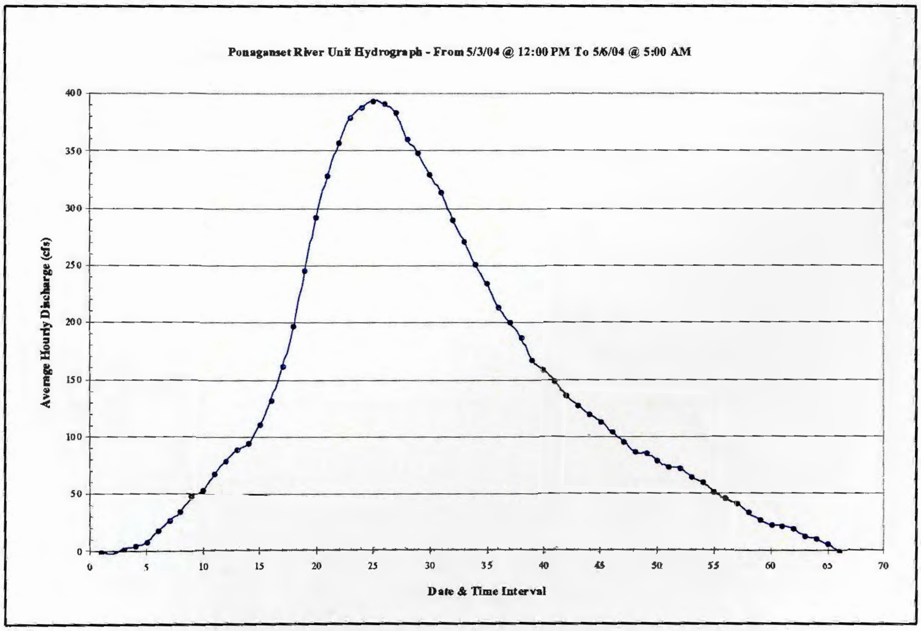
Discharge and Unit Hydrograph Data



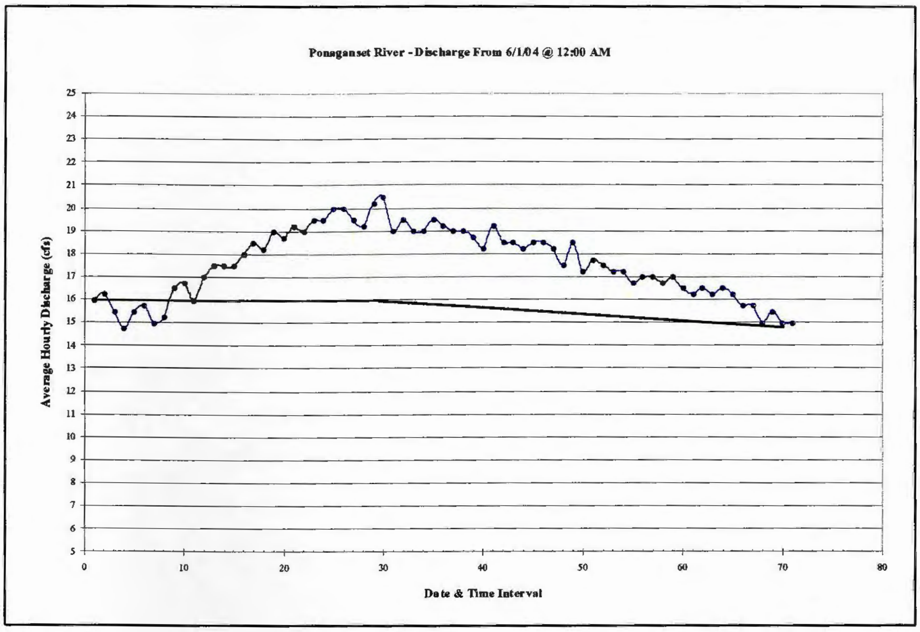


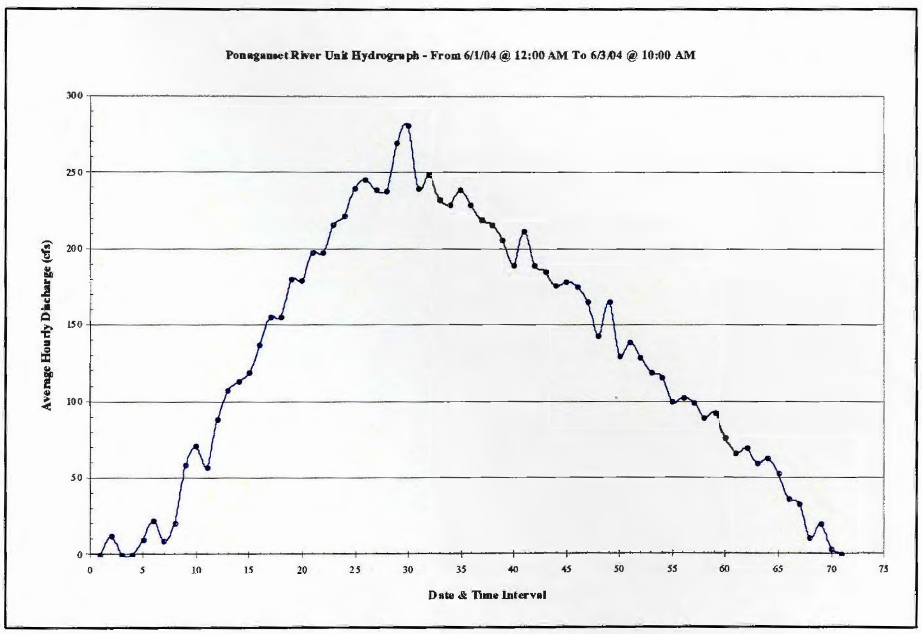


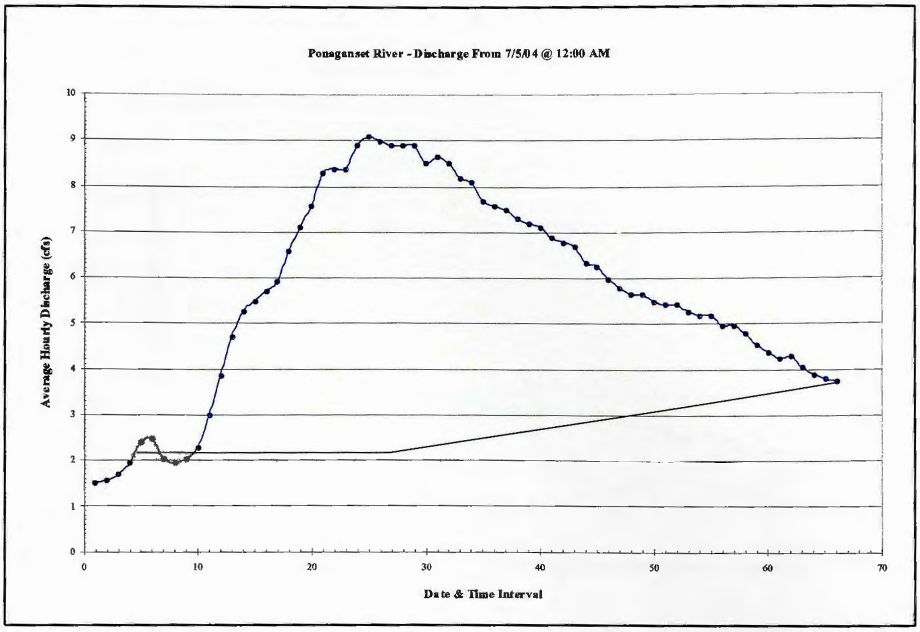
Ponaganset River - Discharge From 5/3/04 @ 12:00 PM
Average Hourly Discharge (cfs)
Date & Time Interval
0
20
40
60
80
100
120
140
160
0
10
20
30
40
50
60
70

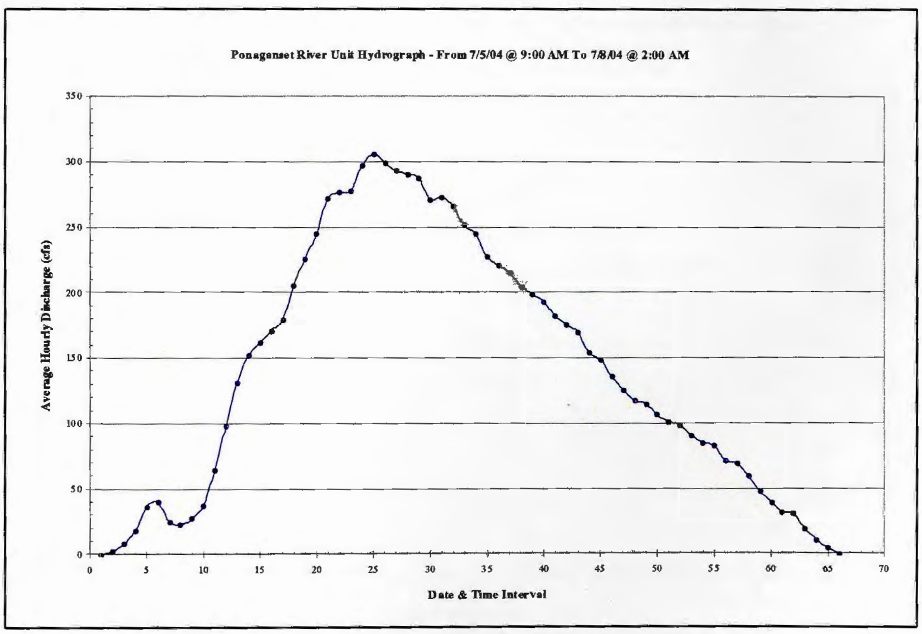


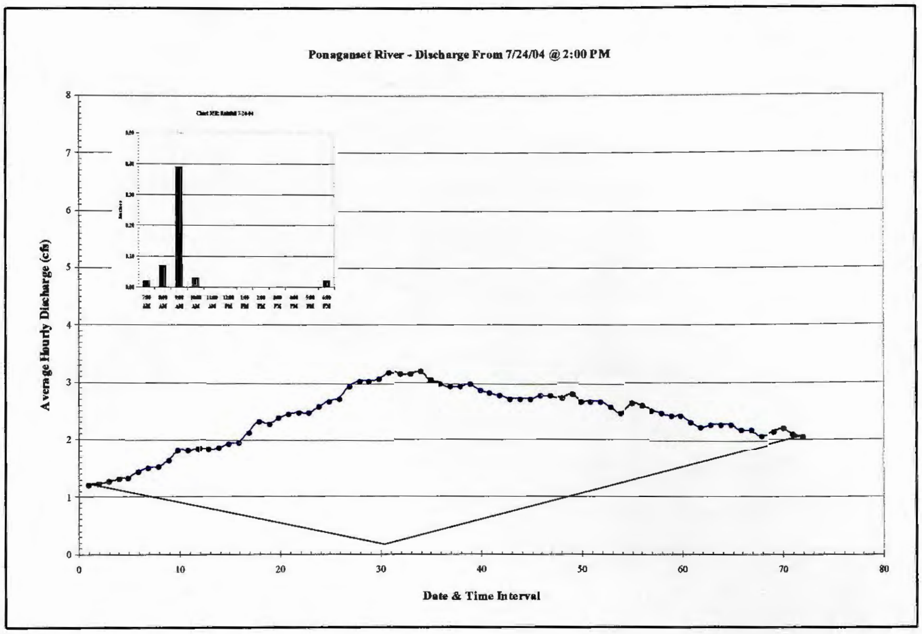
Ponaganset River Unit Hydrograph - From 5/3/04 @ 12:00 PM To 5/6/04 @ 5:00 AM
Average Hourly Discharge (cfs)
Date & Time Interval
0
50
100
150
200
250
300
350
400
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70

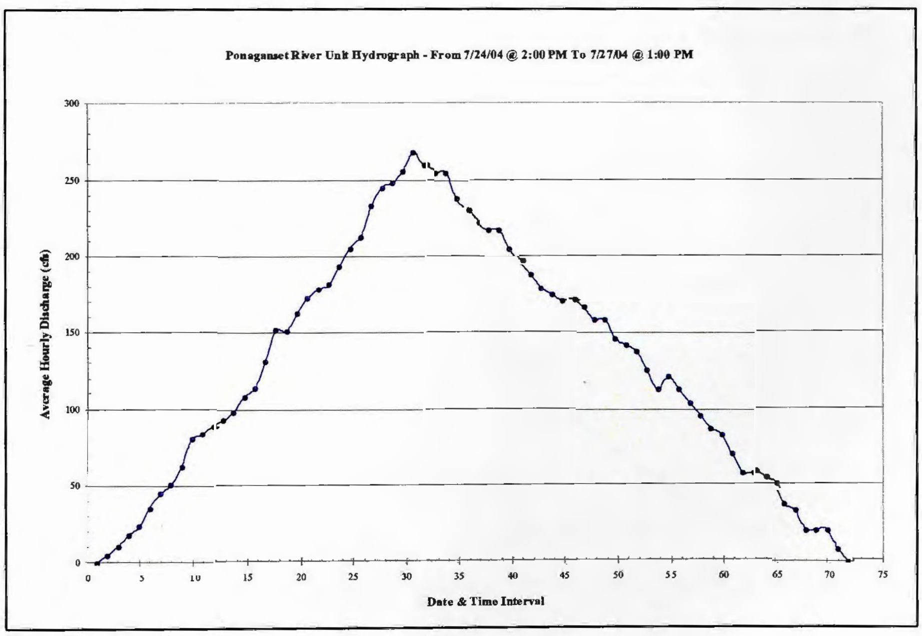

Ponaganset River - Discharge From 6/1/04 @ 12:00 AM
Average Hourly Discharge (cfs)
Date & Time Interval
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
0
10
20
30
40
50
60
70
80

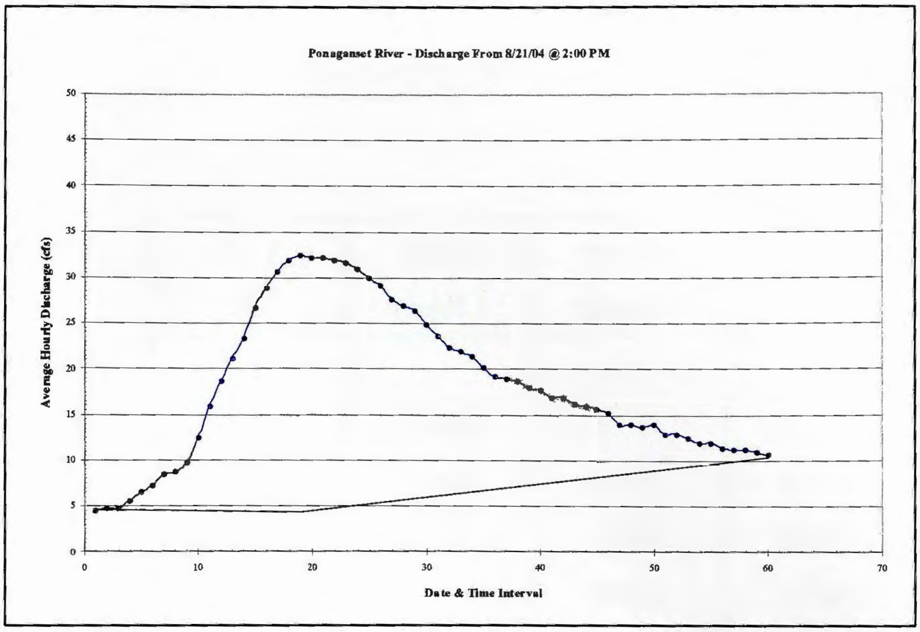

Ponaganset River Unit Hydrograph - From 6/1/04 @ 12:00 AM To 6/3/04 @ 10:00 AM
Average Hourly Discharge (cfs)
Date & Time Interval
300
250
200
150
100
50
0
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75

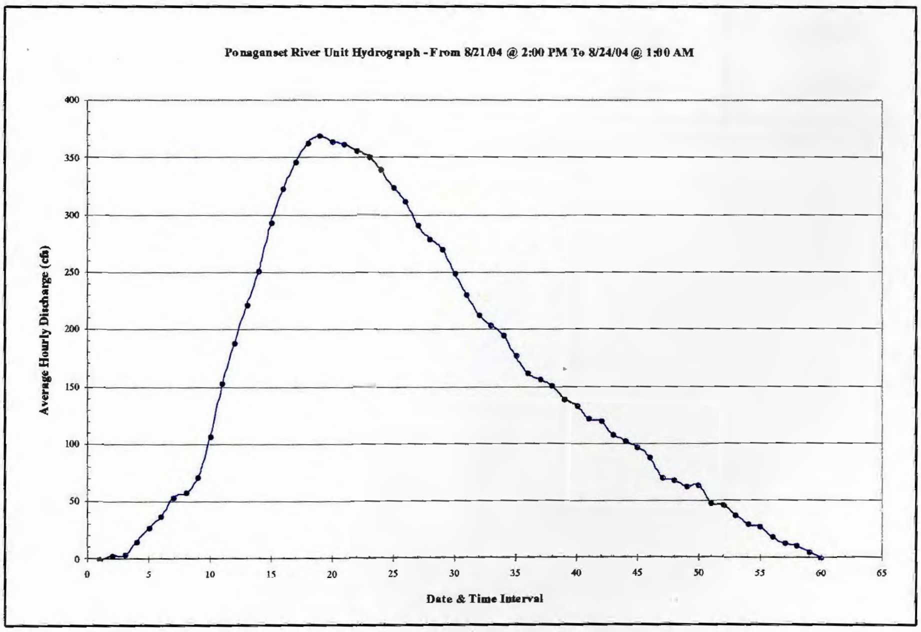

Ponaganset River - Discharge From 7/5/04 @ 12:00 AM
Average Hourly Discharge (cfs)
Date & Time Interval
0
1
2
3
4
5
6
7
8
9
10
0
10
20
30
40
50
60
70


Ponaganset River Unit Hydrograph - From 7/5/04 @ 9:00 AM To 7/8/04 @ 2:00 AM
Average Hourly Discharge (cfs)
Date & Time Interval
0
50
100
150
200
250
300
350
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70


Ponaganset River - Discharge From 7/24/04 @ 2:00 PM
Average Hourly Discharge (cfs)
Date & Time Interval
0
1
2
3
4
5
6
7
8
10
20
30
40
50
60
70
80


Ponaganset River Unit Hydrograph - From 7/24/04 @ 2:00 PM To 7/27/04 @ 1:00 PM
Average Hourly Discharge (cfs)
Date & Time Interval
0
50
100
150
200
250
300
15
20
25
30
35
40
45
50
55
60
65
70
75


Ponaganset River - Discharge From 8/21/04 @ 2:00 PM
Average Hourly Discharge (cfs)
Date & Time Interval


Ponaganset River Unit Hydrograph - From 8/21/04 @ 2:00 PM To 8/24/04 @ 1:00 AM
Average Hourly Discharge (cfs)
Date & Time Interval

APPENDIX E

Historic Concentrations

Date	$Q_{AVG.}$ (cfs)	Zinc (mg/L)	Barium (mg/L)	Manganese (mg/L)
2/6/2002	12.0		0.017	0.027
9/3/2003	9.7	0.028	0.016	0.059
3/1/2004	21.0	0.016	0.016	0.040
6/24/2004	2.9	0.014	0.016	0.038
9/14/2005	0.08		0.030	0.960
Min.		**0.014**	**0.016**	**0.027**
Max.		**0.028**	**0.030**	**0.960**
Avg.		**0.019**	**0.019**	**0.225**

* Historic Samples Tested By: Premier Laboratory using test methods described in Table 5.2

Historic Total Coliform Bacteria (100 mls)

Year	January	February	March	April	May	June	July	August	September	October	November	December
1995	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	3	3
1996	4	3	3	3	23	240		NT	NT	NT	NT	NT
1997	NT	NT	NT	NT	NT	NT	150	75	23	43	43	23
1998	23	3	3	4	3	43	2,400	NT	93	23	4	9
1999	23	9	0	9	23	93	2,400	NT	75	75	43	23
2000	43	NT	0	0	4	75	2,400	NT	460	23	9	9
2001	NT	9	4	15	93	4	23	NT	75	9	9	0
2002	9	4	0	4	9	460	23	1,100	93	150	4	23
2003	9	23	23	4	23	23	2,400	4	2,400	23	23	1,100
2004	0	3	9	9	4	240	2,400	2,400	75	150	1,100	23
2005	4	NT	0	0	0	23	2,400	2,400	23	NT	240	23
2006	15	4	23	9	0	2,400	75	23	9	2,400	43	7
2007	23		0	4	2,400	23	2,400	2,400	NT	NT	NT	NT
2008	9	23	23	43	39	75	2,400	460	240	43	2,400	
Min.	**0**	**3**	**0**	**0**	**0**	**4**	**23**	**4**	**9**	**9**	**3**	**0**
Max.	**43**	**23**	**23**	**43**	**2,400**	**2,400**	**2,400**	**2,400**	**2,400**	**2,400**	**2,400**	**1,100**
Avg.	**15**	**9**	**7**	**9**	**218**	**308**	**1,623**	**1,108**	**324**	**294**	**327**	**113**

* NT = Not Tested

** Note: Historic Total Coliform Bacteria Tested By: PWSB using the Multiple Tube Fermentation Technique.

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